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# DEVELOPMENT OF LIGHTWEIGHT, FIRE-RETARDANT, LOW-SMOKE, HIGH-STRENGTH, THERMALLY STABLE AIRCRAFT FLOOR PANELING

## FINAL REPORT

D. B. Arnold, J. Y. Burnside, and J. V. Hajari

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16. Abstract

Fire resistance and mechanical property tests were conducted on sandwich configurations composed of resin-fiberglass laminates bonded with adhesives to Nomex honeycomb core. The test results were compared to proposed and current requirements for aircraft floor panel applications to demonstrate that the fire safety of the airplane could be improved without sacrificing mechanical performance of the aircraft floor panels.

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# DEVELOPMENT OF LIGHTWEIGHT, FIRE-RETARDANT, LOW-SMOKE, HIGH-STRENGTH, THERMALLY STABLE AIRCRAFT FLOOR PANELING

D. B. Arnold, J. Y. Burnside, J. V. Hajari
Boeing Commercial Airplane Company

## 1.0 SUMMARY

Five different resin systems were tested in combination with either 7581 style woven E-glass fabric or unidirectionally oriented S-glass tow. The resin-glass combinations were tested as face sheets on honeycomb core of the HRH NOMEX$^R$ type or, in the case of one panel, as an integrally woven fluted-core structure.

Smoke and toxic gas generation and impact and flame resistance were determined by testing in an initial screening test phase. Fatigue, flexural properties, and the effect of 14 days' exposure to water immersion, condensing humidity, and salt spray were determined in a final verification testing phase.

Test panels constructed with two-ply face sheets of a Deco, Inc., modified phenolic resin impregnated S-glass tow (XMP 100) exhibited the best overall performance. Panels constructed by General Veneer, Inc., and by Northrop-Pacific, Inc., with the XMP 100 face sheets bonded with flame-retarded epoxy adhesives to Hexcel, Inc., HRH-10 NOMEX$^R$ honeycomb core met the program requirements; however, these panels were marginal in respect to the 1093°C (2000°F) flame exposure requirement (no burn-through or catastrophic failure after 10 minutes' exposure) and the limiting oxygen index requirement (LOI greater than 40). The face sheets, tested by themselves, met the LOI requirements.

Panels constructed with face sheets of polyimide, bismaleimide, and standard phenolic resin systems impregnated on woven glass fabric and bonded to core using a modified form of the face sheet resin system passed the smoke, toxic gas, and flammability tests but failed to meet either the impact test or weight requirements.

## 2.0 INTRODUCTION

The program objectives were to develop lightweight underseat aircraft flooring that would be more fire resistant and generate less smoke and toxicants than the flooring currently used in commercial aircraft. It was required that these objectives be accomplished without compromising the strength, fatigue endurance, impact resistance or other physical properties of the flooring. Other attributes such as simplicity of construction and fabrication, competitive cost in relation to the current flooring, and compatibility with existing mounting techniques and flooring support designs were considered to be desirable but less important than increasing the fire safety of the airplane.

The short work term of the program limited the choice of materials to be included in the study. Potentially viable systems that are currently under development were difficult to obtain in sufficient quantity to be studied in detail. For example, completion of testing of the Narmco materials was prevented by technical difficulties experienced by the Narmco company in preparing a form of their 8250 and 9250 resin systems suitable for impregnating unidirectional glass reinforcements.

The materials tested in this program were selected to provide data on a variety of resin systems, face sheet reinforcements, and sandwich constructions. The data are sufficient to delineate the advantages and disadvantages of the materials as components in aircraft floor panels. Detailed study of all the possible combinations of the selected materials was beyond the scope of this program.

# 3.0 TEST PROGRAM

The program originally consisted of a screening phase (in which the smoke production, flame penetration, and impact resistance of sandwich panel specimens were measured) and a verification phase (in which the fatigue, environmental, and strength properties were measured). Because of the short work term, fatigue and strength tests were often conducted concurrently with the screening tests to save lead time in the event the materials were accepted into the verification test phase. Failure of a panel to meet one or more of the flammability or structural requirements resulted in nonacceptance of the panel into the environmental, oxygen index, and thermal stability test portion of the verification test phase. Twenty-eight panels were accepted into the screening test phase.

## 3.1 PANEL CONSTRUCTIONS

All but two of the panels tested in this program were bonded structures using standard honeycomb core of the phenolic resin impregnated NOMEX$^{R}$ paper (HRH-10), 3.175-mm (0.125-inch) hexagonal cells, 0.08 or 1.3 gm/cm$^3$ (5 or 9 lb/ft$^3$) density. Panel 25 and Boeing panel 3 differed in construction from the other 26.

Panel 25, Gill floor 5166 from the M. C. Gill Corp. was an I-beam fluted structure in which cm (1 in.) wide by 1.27 cm (0.5 in.) high and that ran the length of the panel. Boeing panel 3 used HRH 310 polyimide resin coated NOMEX core.

Bonded honeycomb sandwich panels were fabricated by adhesive bonding of precured laminate or by cocuring the adhesive and the uncured face sheet material.

These and individual panel features such as foam-filled core, polyimide-dipped core, and the use of veil plies are described in table 1. Process details are described in the Appendix (sec. A.1.).

## 3.2 TEST PROCEDURES

The specimen sizes, the minimum number of specimens tested, and any pretest conditioning are stated in this section. The requirements (acceptability criteria) for each test are given in table 2. Test methods that are not described in sections 3.2.1 through 3.2.10 are described in the appendix, sections A.2 through A.7. Photographs of the test equipment are shown in figures 1 through 11.

### 3.2.1 PANEL WARPAGE, WEIGHT, AND THICKNESS MEASUREMENTS

Warpage

Measurements were made on the 0.61- by 1.22-m (2- by 4-ft) panels as received. The panels were placed on a flat table top. A 1.82-m (6-ft) long metal bar was placed across the panel and supported on the ends so that it exerted less than 1.36 kg (3 lb) of weight load on the panel. Separation between the bar and the panel was measured using feeler gages. Measurements were made across both the length and width of the panels.

Weight

The trimmed, squared portions of the panels remaining after the food cart roller test specimens were cut off were weighed on a beam balance having a 4.53-kg (10-lb) maximum capability and a sensitivity of 0.0225 kg (0.05 lb).

Thickness

Individual flexure, burn-through, and FAR 25-32 flame test specimens were measured using a micrometer accurate to 0.00254 mm (0.0001 in.). Individual specimen thicknesses were used to calculate test results where required. The average thickness of all specimens from the same panel was reported as the thickness of the panel.

### 3.2.2 IMPACT STRENGTH TESTS

Impact tests were conducted using the Gardner impact test apparatus described in the appendix (sec. A.2) and shown in figures 1 and 2. The minimum size of the tested piece was 25.4 by 30.48 cm (10 by 12 in.), which was the part remaining after the food cart roller test specimens or the flexure, burn-through, and FAR 25-32 flame test specimens were separated from the panel.

### 3.2.3 FAR 25-32 FLAME TESTS

The FAR 25-32 test requirements are part of the FAA flight certification requirements. Two 12-sec and two 60-sec vertical ignition tests were conducted on specimens cut from each panel. The test specimens were 7.62 cm (3 in.) wide by 33 cm (13 in.) long and were conditioned prior to testing for a minimum of 24 hours at 26° ± 1.5°C (78° ±3°F) and 50% relative humidity.

The tests were performed in the enclosed test chamber shown in figures 3 and 4 and described in the appendix (sec. A.3.).

### 3.2.4 BURN-THROUGH TESTS

The burn-through test was designed to measure the fire barrier capability of wall panel materials. The test materials were mounted vertically and heated on one face by horizontally directed 1093°C (2000°F) gases. The test procedure is described in the appendix (sec. A.4). The test apparatus is shown in figures 5 through 8.

The test specimens were 11.1-cm (4.375-in.) squares of the sandwich panel. The specimens were conditioned for 24 hours in an oven at 60°C (140°F) and then placed in a cabinet at 50% relative humidity and 26°C (78°F) for a minimum of 24 hours prior to testing. At least two specimens from each panel were tested.

### 3.2.5 SMOKE AND TOXIC GAS GENERATION TESTS

The tests were performed in an AMINCO-NBS smoke chamber in accordance with NBS Technical Note 708, "Interlaboratory Evaluation of Smoke Density Chamber," December

1971. Toxic gas generation was determined quantitatively by means of colorimetric tubes (Dräeger) as described in the appendix (sec. A.5). The gases measured were cyanide (HCN), cloride ($HC\ell$), bromide (HBr), and surfur oxides ($SO_2$,$SO_3$).

The test specimens were 7.62-cm (3-in.) squares of the sandwich panels and were conditioned prior to testing for 24 hours in an oven at 60°C (140°F) and then placed in a cabinet at 50% relative humidity and 26°C (78°F) for a minimum of 24 hours. At least four specimens from each panel were tested.

The test procedure is described in the appendix (sec. A.5). Figure 9 is a photograph of the test chamber.

### 3.2.6 LIMITING OXYGEN INDEX (LOI) TESTS

Limiting oxygen index tests were determined in the oxygen-nitrogen test apparatus shown in figure 10. The tests were conducted in conformance with ASTM D2863T.

The specimens were 150 mm (6 in.) long by 6.5 ± 0.5 mm (0.26 ± 0.01 in.) wide and 3.0 ± 0.5 mm (0.125 ± 0.01 in.) thick. Since it was impractical to slice the sandwich to these dimensions, the face sheet, face sheet plus adhesive, and the core were tested separately.

The test procedure is described in the appendix (sec. A.6).

### 3.2.7 FATIGUE (FOOD CART ROLLER) TESTS

Fatigue resistance was determined in the Boeing designed and built roller test fixture shown in figure 11. The test simulates the panel loading imposed by the wheels of food and beverage carts used by the airlines. The test has provided useful correlation between the service life of Boeing aircraft aisle panels and the number of rolling cycles the same type of panels endure in the cart roller tester.

Two test panels, each 54.1 cm (21.3 in.) wide by 99.8 cm (39.3 in.) long were mounted on a 747 airplane aisle configuration support structure. Three Bassick casters (rollers) were mounted on a load weight pan, in a 50.8-cm (20-in.) diameter circle with 120° spacing. The 50.8-cm (20-in.) diameter wheel track was centered over the two panels in the 99.8-cm (39.3-in.) direction and cycled a 25.4-cm (10-in.) radius semicircle on each panel. The panels were cycled for a minimum of 115 000 cycles at a given load weight. The load weight was then increased and the cycling continued until failure occurred at the increased load weight. Underseat panels were initially exposed to 30.4 kg (67 lb) per wheel loading. Since damage was practically nil, the 30.4-kg (67-lb) loading requirement was dropped and tests started with 44.5 kg (98 lb) loading. Only those panels that survived were exposed to 58 k (128 lb) per wheel loading. Aisle panels were tested under 58 and 71.6 kg (128 and 158 lb) per wheel loading. Failure was considered to have occurred when skin puncture or core failure was visible.

Even though the underseat floor panel.is not exposed to the food cart loading, the test fixture is used to obtain comparative fatigue test data.

### 3.2.8 FLEXURE TESTS

The panel bending load capability was determined in long beam bending in accordance with MIL-STD-401, A, "Sandwich Configurations and Core Materials: General Test Methods." A Tinius-Olsen Universal test machine equipped with a proportional recorder was used. Deflections were measured by using a Tinius-Olsen D2 deflectometer.

The test specimens were sandwich beams 7.62 cm (3 in.) wide by 60.9 cm (24 in.) long. The beam ends were supported at points 50.8 cm (20 in.) apart. The load was applied downward through two load bars at points ¼ span from the support points. Deflection at a 45.3-kg (100-lb) load and the ultimate breaking load were determined.

### 3.2.9 ENVIRONMENTAL EXPOSURE TESTS

The effect of 14 days' exposure to condensing humidity, to water immersion and to salt spray was determined. The procedures are described in the appendix (sec. A.7.).

The condensing humidity and water immersion specimens were 7.62 cm (3 in.) wide by 33 cm (13 in.) long. At least five specimens cut from each direction (longitudinal and transverse) of the panel were exposed. Peel and flatwise tensile tests were performed on the specimens after exposure.

The salt spray specimens were 5.08-cm (2-in.) square specimens. The specimens were examined and photographed at 10X magnification before and after exposure to determine if the salt spray exposure produced pitting, staining, bleaching, milking, etching, or other evidence of corrosion.

### 3.2.10 CHEMICAL/THERMAL TESTS

Specimens 25.4 cm (10 in.) wide by 38.1 cm (15 in.) long were placed in a circulating air oven that had been preheated to 204°C (400°F). The specimens were removed from the oven after 30 minutes and examined for visible heat damage.

Additional sandwich specimens weighing 35 to 48 mg were subjected to pyrolysis in a Mettler thermal balance (TGA). A standard air atmosphere was maintained in the test cell, and the temperature of the test cell was raised at a rate of 6°C (11°F) per minute until weight loss ceased to occur.

## 3.3 MATERIAL PERFORMANCE REQUIREMENTS

The performance requirements are those of a light traffic (underseat) type of panel. This is designated in the report as a type 1 panel. The current form of type 1 panels is an epoxy resin impregnated, two-ply, unidirectional glass reinforced face sheet on a 80.4 $kg/m^3$ (5-$lb/ft^3$) NOMEX[R] paper core. A heavier duty core, 144.3 $kg/m^3$ (9 $lb/ft^3$), is used with the same face sheet construction for heavy traffic (aisle and galley) areas. This is designated in the report as a type 2 panel.

Performance data for type 1 panels (13) and type 2 panels (14 and 15) are given in various places in the report as reference or as baseline levels for comparison.

# 4.0 TEST RESULTS

## 4.1 DATA PRESENTATION FORMAT

Data groups are presented in table 2 to permit easier visualization of the differences between panels. The individual values of test data are presented in tables 3 through 7.

The panel numbering system is used for convenience of reference in the text. The panels are further identified on the charts by use of the manufacturers' names.

Significant features of the data groups are discussed, but for the most part the discussions center around photographs of the actual test specimens.

## 4.2 PRESENTATION AND DISCUSSION OF RESULTS

The data on panels 6, 9, and 10 are limited to only a few tests because of the small size of the panels furnished.

### 4.2.1 PANEL WEIGHT, WARPAGE, AND THICKNESS DATA

The first three columns in table 2 show panel weight, warpage and thickness. The Ciba-Geigy panels 9, 19, and 20 were constructed with three-ply, resin impregnated 1581 glass fabric face sheets. The three-ply face sheets were needed to enable the panels to meet the impact strength requirement. As a result panels 9, 19, and 20 exceeded the weight requirement. Panels 19 and 20 were the only available panels using the Ciba-Geigy DLS 438 low-smoke phenolic resin system, and they provided a comparison of the fire properties of phenolic foam-filled core versus empty core sandwich construction. They were therefore placed in the flammability screening tests.

The weights of the candidate panels are compared in table 2 with the weights of currently used floor panels that have epoxy resin impregnated face sheets. Type 1 (underseat) panels use 80.1-kg/m$^3$ (5-lb/ft$^3$) core and average 2.39 kg/m$^2$ (0.49 lb/ft$^2$) (panel 13). Type 2 (aisle) panels use 144.3-kg/m$^3$ (9-lb/ft$^3$) core and average 3.03 kg/m$^2$ (0.62 lb/ft$^2$) (panels 14 and 15).

The experimental low-smoke panel weights are higher than the current type 1 and type 2 epoxy resin base panels. However, all panel weights are within the 3.4-kg/m$^2$ (0.70-lb/ft$^2$) maximum weight requirement of the test program except for the three woven fiberglass Ciba-Geigy panels (9, 19, and 20).

The weight differences are most marked among the type 1 panels using 80.1-kg/m$^3$ (5-lb/ft$^3$) core. The experimental type 1 panel constructions tested in this program ranged from 2.73 to 3.17 kg/m$^2$ (0.56 to 0.65 lb/ft$^2$) compared to 2.39 kg/m$^2$ (0.49 lb/ft$^2$) for panel 13, a typical type 1 panel of current design.

The experimental type 2 panels (10, 21, and 22), which use 144-kg/m$^3$ (9-lb/ft$^3$) core, are only slightly heavier than the current epoxy base type 2 (panels 14 and 15).

The panel thicknesses are compatible with current mounting space requirements. The panels were uniformly flat and met the program warpage requirement of 0.21 cm/m (0.025 in/ft).

### 4.2.2 IMPACT STRENGTH TEST RESULTS

Impact strength data are presented in column 4 of table 2. The impact strength of panels with unidirectionally reinforced face sheets generally exceeded 0.35 kg·m (50 in-lb) of energy. The unidirectionally reinforced panels 17 and 18, which were fabricated with a veil of glass mat (angel hair) between the face sheet plies, resisted striking energies of 1.04 kg·m (90 in-lb) and higher. The impact strengths of the unidirectionally reinforced panels were so much greater than the program requirement of 0.35 kg-m (30 in-lb) that it was necessary to use a 1.81-kg (4-lb) dart in the Gardner impact tester to generate energies great enough to fail the panels.

The panels fabricated with two-ply woven glass fabric face sheets failed to resist the required minimum of 0.35 kg·m (30 in-lb) of energy. Panels 19, 20, and 22, which were fabricated with three-ply woven glass face sheets, did meet the requirement but panels 19 and 20 both exceeded the 3.42-kg/m$^2$ (0.70-lb/ft$^2$) weight limitation. The woven glass fabric reinforced panels were tested using a 0.9 kg (2-lb) dart in the Gardner impact tester.

It was observed that the unidirectionally and woven fabric reinforced face sheets failed by different modes. The unidirectionally reinforced face sheets split and tended to delaminate in the areas adjacent to the impacted point. Figures 12 and 13 show this effect. The woven fabric reinforced face sheets punctured cleanly as shown in figure 14. The circled values on the illustrated specimens are the impact failure energies in inch-pounds.

The two types of face sheets differ in respect to glass content – the unidirectionally oriented face sheets having higher glass content – and often in respect to processing. (See table 1.) However, since the unidirectionally reinforced panels differ in these respects among themselves and yet uniformly resisted high impact energies, the difference in the energy levels at failure is the more likely reason for the difference in failure mode. In any case, it must be concluded that the unidirectional construction is inherently more impact resistant than the woven constructions tested in this program.

### 4.2.3 FAR 25-32 FLAME TEST RESULTS

Extinguishment times are given in columns 5 and 6 of table 2 and burn length data are given in columns 7 and 8 of table 2. The specimens were tested in the composite (sandwich) form.

#### Extinguishment Times

Panels 7, 16, 17, 18, 23 and 24 failed to extinguish within the required 15 sec either in the 12-sec or 60-sec ignition test. The panels all use the same adhesive (Narmco-Metalbond 1133) and were fabricated and submitted in pairs differing only in the weight of adhesive. Panels 7, 18, and 24 were bonded using 0.29 kg/m$^2$ (0.06 lb/ft$^2$) of adhesive. Panels 16, 17, and 23 were bonded using 0.17 kg/m$^2$ (0.035 lb/ft$^2$) of adhesive. The first pair, panels 7 and 16, used two-ply Deco (XMP-20) face sheets that had resin contents of 15% to 19% by weight. The second pair, panels 17 and 18, used two-ply Deco (XMP-20) face sheets that had resin contents of 22% to

25% by weight. The third pair, 23 and 24, used a proprietary Panel Air "Low Smoke" (LS) resin system in the two-ply unidirectionally reinforced face sheets. Resin contents in the face sheets of the third pair were over 30% by weight. It is apparent that the adhesive used in bonding panels 7, 16, 17, 18, 23, and 24 is responsible for the excessive extinguishment times. This is confirmed by comparison with the extinguishment times of panels 6, 10, 21, and 26 which used the same face sheets and core but different adhesives (table 2).

Burn Length

The visible damage to all specimens exposed to the 12-sec vertical burn test was within the 20.32-cm (8-in.) maximum burn length required by the FAR 25-32 test method.

The 60-sec vertical burn test requires that the burn length be a maximum of 15.24 cm (6 in.). Specimens cut from panel 10 failed to meet this requirement. Panel 10 was submitted for testing in the screening phase by Northrop-Pacific. Northrop-Pacific supplied verification material as panel 21. General Veneer supplied vertification material as panel 26. Specimens cut from panels 26 and 21 passed the 12-sec and 60-sec vertical burn test requirements in respect to both the burn length and the extinguishment times.

The effect of the core and adhesive on both the visible and internal burn damage is shown in figures 15 and 16. Figure 15 shows that the visible face sheet damage of sandwich specimens using Deco XMP face sheets (panels 21 and 26) was greater than the damage suffered by a test specimen of XMP face sheet only (1-1). Section views of the same sandwich test specimens are shown in figure 16. The internal damage was extensive and the full extent of damage to the core was not always determinable by scraping the skin and inspecting the visible face sheet damage.

Figure 17 compares the resistance to the FAR 25-32 type test of the resin systems tested in this program as sandwich specimens. Laminate test specimen 1-1 is included to provide comparison with figure 15.

#### 4.2.4 BURN-THROUGH TEST RESULTS

Column 9 of table 2 summarizes the heat transmission and heat contributions of 11.11-cm (4.375-in.) square sandwich specimens exposed to single face heating for a period of 10 min. The backface (face protected from the heat source) temperatures shown in column 10 of table 2 are the temperatures reached at the end of the 10-min test run. The maximum heat contribution rates, $Q_{max}$, attained during the portion of the test run over which burning or thermal decomposition occurred are given in table 4. The tests were continuously monitored by a Varian recorder. Typical curves of burn test temperature development are shown in figures 18 through 21.

Generally stated, most of the specimens ceased burning or reacting after 2 to 3 min. A few, such as panel 15, epoxy base system, continued reacting for as long as 7 min. Panels 7, 16, 17, 18, and 23, for example, reacted throughout the entire 10-min run.

The exposed faces were burned free of the impregnating resin but in some cases a heavy carbon deposit remained. (See figs. 22 and 23.) Internal damage was severe, as shown in the section views in figures 24 and 25. It is notable that damage to the sandwich core appears to

be associated with the degree of burning that occurred at the adhesive bond between the face sheet and the core. This parallels the results found during the FAR 25-32 burn tests and emphasizes the fact that the adhesive bond ply is currently one of the weakest elements in respect to flame resistance of the sandwich constructions tested in this program.

The backface temperatures at the end of the test were all disappointingly high, especially since these temperature levels were, for all practical purposes, attained by the end of the first 5 min of testing. Some specimens did not exceed 260°C (500°F), but examination of the sectioned specimens provides evidence that failure of the exposed face sheets to remain bonded may have caused a reduction in heat transmission through the specimens. The extent of backface damage associated with the measured backface temperatures is shown in figures 26 and 27; the darker the area, the greater the thermally induced damage.

### 4.2.5 SMOKE AND TOXIC GAS GENERATION TEST RESULTS

#### Smoke Generation

The smoke generation data are presented in columns 11, 12, and 13 of table 2. The data are arranged in sets of three values for each panel. The first two values (columns 11 and 12) are the optical density ($D_s$) for 1.5 and 4 min after start of the test. The third value in each set is the maximum value of $D_s$ reached after 4 min and within 20 min after start of the test. The tests were conducted in the flaming mode. $D_s$ values were calculated from the measured transmission loss as described in the procedure in the appendix (sec. A.5.).

All the new systems except the Northrop-Pacific low-smoke system (panel 22) generated significantly less smoke than the current panels based on epoxy resin systems (panels 13 and 14). Reduced smoke generation was expected, based on previous NASA testing of phenolic, polyimide, and bismaleimide resin systems in other than sandwich configuration. The extremely low smoke generation of the bonded sandwich panels is surprising in view of the known use of epoxy resin base adhesives in some of the panels – panels 6, 7, 16, 17, and 18, for example.

#### Toxic Gas Generation

The highest measured levels of HCN and HCl gases were on the order of 6 to 7 parts per million. These levels were found for the baseline, epoxy resin type panels. The Northrop-Pacific LS system, panel 22, evolved an accumulation of 3 parts per million of HCN. All the other panels evolved 1 part per million or less of HCN, HBr, HCl, and sulfur oxides.

### 4.2.6 LIMITING OXYGEN INDEX (LOI) TEST RESULTS

The three panels (21, 23, and 26) selected for the verification phase were subjected to burning in the LOI test. The face sheet material, the face sheet plus adhesive, and the core materials were tested separately because of the limitations of the test method described in section 3.2.6. Face sheet and adhesive from panel 14 were also tested to afford a comparison with a floor panel of typical current design. Only the Deco (XMP-100) face sheet material when tested alone meets the requirements of LOI greater than 40, as shown in figure 28.

The separate testing of the sandwich structural elements provides a clear picture of the performance of the individual elements. A knowledge of how the individual elements perform provides the guide to further improvements. The data for panels 21 and 26 illustrate the point. Panels 21 and 26 were fabricated with the Deco XMP-100 face sheet material and bonded with epoxy resin adhesive systems. The Deco face sheet material burns in 100% oxygen for only as long as the ignition flame is applied. When tested with the epoxy adhesive attached, the combination burns in 37% to 38% oxygen and continues to burn after removal of the ignition flame.

### 4.2.7 FATIGUE (FOOD CART ROLLER) TEST RESULTS

Columns 14, 15, and 16 in table 2 present the fatigue test data on the baseline and experimental panels. Reference to the baseline panels shows that the Ciba-Geigy epoxy resin based type 1 (panel 13) survived 115 000 or more cycles at a wheel (roller) loading of 44.4 kg (98 lb). Taking into account the variances in configuration and hardness of the roller test wheels, panels surviving 112 000 to 113 000 cycles can be considered acceptable.

Excellent fatigue resistance was demonstrated by panel 1 (Boeing), panel 26 (General Veneer), and panel 23 (Panel Air). Panel 21 (Northrop-Pacific) demonstrated acceptable fatigue resistance. These four panels survived cycling at wheel loadings higher than 44.4 kg (98 lb). The Northrop-Pacific panel (21), shown in figure 29, is typical in appearance of the tested panels.

### 4.2.8 FLEXURE TEST RESULTS

The ultimate beam loads and the deflection at 45.3 kg (100 lb) for sandwich specimens 7.62 cm (3 in.) wide by 60.96 cm (24 in.) long are listed in table 2 and 6. The data indicate that the experimental resin systems used in the face sheet will meet the strength and deflection requirements for floor panel applications.

### 4.2.9 ENVIRONMENTAL EXPOSURE TEST RESULTS

Three systems panels 21, 23, and 26 were subjected to condensing humidity, distilled water immersion, and salt spray exposure. Selection of the systems to be tested was based on the following considerations:

1. Results of the fatigue (food cart foller) tests

2. Results of the smoke and toxic gas generation tests

3. Results of the FAR 25-32 tests

4. Results of the impact tests

Flexural strength was not a deciding criterion because the ability of all the panels to meet the bending load and deflection requirements was demonstrated by test. The use of resistance to

burn-through and heat transmission properties as deciding factors would have ruled out the panels showing the best fatigue and impact performance. Improved adhesive and possibly improved core materials will be required to completely satisfy the flame barrier requirements, regardless of panel choice.

The selected systems meet the program requirements for the four listed criteria with one exception. The Panel Air system (panel 23) is marginal in respect to the 12-sec vertical burn test, which has been shown to be a function of the particular adhesive system used and could be remedied.

### Condensing Humidity Tests

The weight gain and flatwise tensile data are shown in table 7. Changes in weight and peel strength are compared in figure 30. The flatwise tensile strength of the exposed specimens is shown in figure 31 in comparison with the flatwise tensile strength of the unexposed (control) specimens. The decreased flatwise tensile strength found for the candidate panels 21, 23, and 26 test groups are evidence that exposure to humidity affects the skin-core bond strength since inspection of the specimens revealed that the mode of failure was skin-core bond failure. All three low smoke candidate panels gained more weight than the reference panel 14, a typical epoxy base, NOMEX core panel of current design.

### Distilled Water Immersion

The weight gain data shown in table 7 and summarized in figure 30 include the water immersion data. The flatwise tensile strength of the exposed water immersion specimens is shown in figure 31 The control test data are shown in figure 32. The three candidate panels 21, 23, and 26 gained only slightly more weight than reference panel 14. Panel 23 alone showed decreased strength after exposure. Upon visual inspection of the tested specimens, the very low flatwise tensile values measured for individual test specimens from panel 14 and 21 were found to be due to poor adhesive filleting of the core. The low values were included in the group average reported in table 7.

### Salt Spray Exposure

No resin crazing or milkiness was observed at 10X after exposure. No pitting of the reinforcing fibers was found. The only effect appeared to be a darkening of the resin used in panel 23. Typical appearance before and after test is shown in the 10X microphotograph views of figures 33 and 34.

## 4.2.10 CHEMICAL/THERMAL TEST RESULTS

### Oven Exposure to 204°C(400°F)

The 0.93-m$^2$ (1-ft$^2$) sandwich sections were tested for the ability to remain integrally bonded when exposed to heating in a preheated, circulating air oven. The face sheets of panels bonded with adhesive other than the Narmco 9250-112 adhesive and the American Cyanamid BR-34B-18 adhesive began to unbond within 15 min after start of the test. At the end of 30 min, all except the BR-34B-18 bonded panels were severly warped. The face sheets were not damaged or delaminated but had become almost completely separated from the core.

Thermogravimetric Tests (TGA)

Specimens of panels 14, 21, 23, and 26 were pyrolyzed in a Mettler thermal balance (TGA). The test specimens were ground samples of the sandwich weighing 30 to 48 mg. A standard air atmosphere was maintained in the test cell, and the cell was heated at 6°C/min (10.8°F/min). The change in the sample weight was automatically measured and continuously recorded on a chart. The temperature regime of interest extends from the temperature at which weight loss began to the temperature at which weight loss ceased. The temperatures at which significant events occurred are shown in table 8.

The results in table 8 primarily reflect the stability of the face sheet material. The bulk of the sample weight comes from the face sheet. Panel 14 is a reference panel typical of the current epoxy resin base type. Panels 21 and 26 use the Deco (XMP-100) face sheet resin system. Panel 23 is the Panel Air low-smoke resin system.

# 5.0 CONCLUSIONS AND RECOMMENDATIONS

## 5.1 CONCLUSIONS

The following conclusions are based on the data presented in table 9.

1. Face sheets of modified phenolic (Deco XMP 100) impregnated S-glass tow meet all of the program requirements. Sandwich panels constructed of XMP 100 face sheets bonded to HRH-10 NOMEX$^R$ honeycomb core with epoxy adhesives are severely damaged after 10 minutes' exposure to 1093°C (2000°F), flame, but the sandwich panels meet the program requirements in all other respects.

2. The face sheets meet the LOI requirement of the program when tested by themselves. When tested in combination with the epoxy adhesives, the system does not meet the program requirement of 40 minimum. When tested alone, the HRH-10 core does not meet the LOI requirement.

3. Smoke generation levels are within the 75 maximum $D_s$ requirements, but an effort should be made to develop face sheet plus adhesive combinations that are less marginal in respect to the flammability requirements.

4. Firm allowable levels for toxic gas emission do not exist at present. The levels of HCN, HCR, HBr and sulfur oxides measured during the smoke chamber runs were 8 parts per million or less.

## 5.2 RECOMMENDATIONS

The following recommendations are made:

1. It is recommended that development continue on underseat panels, using the same screening and verification criteria as were used in this program. Because of the short work period of the initial contract, some viable systems could not be procured and tested in time. Other systems were eliminated because of higher than anticipated procurement costs. Systems such as FX-resin from Air Transmission, Fiberite MXB 6070, duPont 6113-1, and Hexcel 530, as well as fluted core from Hitco, merit consideration for inclusion in a future program.

2. The original contract examined the floor panel systems in terms of flammability, static and fatigue strength, and environmental durability. It is proposed that additional tests be run to fully characterize approximately five candidate systems. Mechanical strengths would consist of measuring fastener insert pullout strength and panel inplane shear strength.

In addition, another family of tests is recommended in which coupons would be exposed to a fire while under a stressed condition or the residual strength of coupons would be measured after exposure to a high heat flux or open fire. Figure 35 shows three test configurations that could be considered.

3. The present contract emphasized a low-traffic (underseat) type of panel. It is recommended that the technology base be expanded to include high-traffic (aisle and galley) types of panels. Development would include selecting promising candidate systems from from the initial contract work, increasing the core densities and face sheet thicknesses (if necessary), and testing at more stringent fatigue loads.

4. It is recommended that a final configuration be delivered to an airline for service evaluation.

Boeing Commercial Airplane Company
P. O. Box 3707
Seattle, Washington 98124
April 20, 1976

# APPENDIX

# EQUIPMENT AND DETAILS OF PROCEDURES

## A.1. ADHESIVE BOND PLY

Northrop-Pacific, Inc., and General Veneer, Inc., used proprietary adhesive formulations to bond their face sheet material to the core. General Veneer indicated that they used an epoxy resin type of adhesive, but no other identification or definition of the formulation was disclosed.

Panel Air Corp. identified their adhesive as Metalbond 1133, a Narmco, Inc., epoxy-type adhesive.

Ciba-Geigy identified their adhesive bond ply as a 120 style E-glass fabric, preimpregnated with the same phenolic resin system used in their face sheet plies (DLS 428 series).

The Boeing Company explored the use of two different types of adhesives. One type was a bond ply of 112 style E-glass fabric, preimpregnated with Narmco 9250 resin system (initial trials) or Narmco 9251 resin system (later trials). These resin system formulations are proprietary to Narmco, Inc. The second type of adhesive used by The Boeing Company was a polyimide paste adhesive, American Cyanamid BR-34B-18 (Boeing Material Specification BMS 5-84). Adhesive weight control was achieved by spreading a weighed amount of the paste on a precured skin of known surface area.

Panel Air Corp. and General Veneer, Inc., obtained precured (press-laminated) face sheets of Deco XMP (described as a modified phenolic) resin impregnated collimated S-glass tow. Two plies of the face sheet material, oriented at 0° to 90°, were pressed to a cured thickness of 0.036 to 0.041 cm (0.014 to 0.016 in.). Resin content of the cured sheets ranged from 16% (for some initial panels submitted to The Boeing Company for test) to 26% resin by weight. Panel Air Corp. and General Veneer, Inc., bonded the precured face sheets to the HRH-10 core using an adhesive. The panel assembly was cured in a separate press-laminating cycle.

Northrop-Pacific, Inc., obtained the Deco XMP face sheet material in uncured form and co-cured the face sheet and the adhesive bond plies to the HRH-10 core in a single press-laminating cycle. The face sheet layup was two plies with 0° to 90° orientation of ply warps.

The Boeing Company obtained precured Deco XMP face sheets and bonded the face sheets to the HRH-10 core using a Narmco 9250-112 adhesive and a vacuum bag, oven cure cycle at 127°C (260°F). The face sheet layup was two plies with 0° to 90° orientation of the warp direction.

The Boeing Company also obtained uncured preimpregnated 7581 E-glass fabrics from Narmco, Inc. (8250 resin system) and from E.I. duPont deNemours & Co. (polyimide system PG 6003) and cocured the face sheet and adhesive bond plies. The 8250-7581 was cocured with 9250-112 using a vacuum bag, oven cure cycle of 127°C (260°F) for 90 min. The 7581-

PG 6003 was cocurred with American Cyanamid BR-34B-18 using a vacuum bag, oven cure cycle at 177°C (350°F) for 90 min. Face sheet layups were two plies, 0° to 90° orientation of fabric warp.

Ciba-Geigy, Ltd., did not specify their process beyond the information that the panels were cured in a vacuum bag at 132°C (270°F). They identified their resin system (DLS 428 series) as a phenolic resin system. The face sheet reinforcement was woven E-glass fabric.

M. C. Gill Corp. did not define the process for fabricating their woven structure panels. They identified their resin as a phenolic resin system. This integrally woven structure did not require adhesive bonding.

## A.2. IMPACT STRENGTH

Impact strength was determined by using the Gardner impact test fixture shown in figure 1.

The impact point was a steel rod tapered conically to a 3.175-mm (0.125-in.) flat face at the panel contact end as shown in figure 2. The projectile was a 0.91- or 1.82-kg (2- or 4-lb) weight as required to achieve failure impact forces. The test specimens were impacted at 4.6-kg • cm (4-in-lb) force intervals until failure occurred, and the failure force was determined to within 2.3 kg • cm (2 in-lb) Failure force was taken to be the minimum force at which the impact tool punctured the face sufficiently to permit a freshly sharpened writing pencil point to pass completely through the face sheet at the point of impact under light hand pressure. Impact tests were made on the portion of the panel remaining after the cart roller test specimens were cut off or on the portion remaining after the flexure, burn-through, and FAR 25-32 flame test specimens were cut off. The minimum size of the tested piece was 25.4 by 30.48 cm (10 by 12 in.) in either case.

## A.3. FAR 25-32 FLAME TESTS

The FAR 25-32 flame tests are required by the Federal Aviation Agency for flight hardware certification. In accordance with FAR 25-32, paragraph 8, 12- and 60-sec vertical ignition tests were conducted. The procedure is described in the following paragraphs and a typical test setup is shown in figures 3 and 4.

The bunsen burner was operated on commercial propane gas supplied from a storage tank at a line pressure of 26.67 cm (10.5 in.) of water. The flame was adjusted to give a temperature of 871° ±10°C (1600° ±50°F) with a flame height of 38.1 mm (1.5 in.) total and a blue cone height of 19.05 mm (0.75 in.) high. Flame temperature was measured by using a Leeds & Northrup model 8659 bridge-type potentiometer and chromel-alumel thermocouple that was mounted to the specimen holder flame for accurate positioning during the measurement.

The specimens were mounted vertically as shown in figure 4. Two specimens were tested at each of the test conditions, 12- and 60-sec vertical ignition. The time during which the burner flame was applied to the specimen and the time of specimen burning following removal of the burner flame were measured by using an electric timer accurate to within 0.1 sec. Burned length was determined by scraping the charred area with a scalpel blade to

find the end of the damaged area and measuring with a steel scale graduated in 0.025-cm (0.01-in.) increments.

Two 12-sec and two 60-sec vertical ignition tests were conducted on specimens cut from each panel. The test specimens were 7.62 cm (3 in.) wide by 33 cm (13 in.) long and were conditioned prior to testing for a minimum of 24 hours at 26°C ±1.5°C (78°F ±3°F) and 50% relative humidity.

## A.4 BURN-THROUGH TESTS

Resistance of the candidate panels to penetration by a 1093°C (2000°F) flame was determined in the Boeing test apparatus shown in figures 5 through 8. The operating conditions during the tests and the test procedure are described in the following paragraphs.

### OPERATING CONDITIONS

The operating conditions were adjusted to provide a heated gas temperature of 1093° ±37.8°C (2000° ±100°F) and an incident heating rate of 8.52 to 10.2 $W/cm^2$ (8.5 to 9 $Btu/ft^2$-sec) at the position of the center of the exposed face of the test specimen. Initial settings were made with a Hycal water-cooled colorimeter mounted through a hole in an insulating baffle placed in the test specimen position.

The gas temperature was measured by the platinum-platinum (13%) rhodium thermocouple shown in figure 6 located in front of the center of the specimen window. Thermocouple and colorimeter outputs were recorded by the Varian recorder shown in the lower right-hand corner of figure 5. The heating source was a Meeker blast burner fed with commercial propane gas premixed with air at the burner. The gas was fed at 26.67 cm (10.5 in.) of water pressure.

The specimens and the glass wool filter were reweighed at the completion of the test. The weight loss of the specimens was used to estimate an average heat contribution per unit weight of material consumed. The heat released was calculated by comparing the increase in temperature of the exhaust (stack) gases during the period the material burned or pyrolyzed (reacted) with the increase of the exhaust gas temperature produced by burning various measured flow rates of propane gas. The gas was burned in a multijet burner that is mounted in the test chamber during the calibration but not during an actual test run.

The test specimens were 11.1-cm (4.375-in.) squares of the sandwich panel. The specimens were conditioned for 24 hours in an oven at 60°C (140°F) and then placed in a cabinet at 50% relative humidity and 26°C (78°F) for a minimum of 24 hours prior to testing. At least two specimens from each panel were tested.

Typical curves are shown in figures 18 through 21.

The gas flow rate was measured by a Fischer-Porter flowmeter. The premix air was fed at 0.68-atm (10-psi) pressure. Additional air was introduced into the test chamber through a perforated plate at the bottom of the chamber. The perforated plate.airflow was measured by a Fischer-Porter flowmeter. In operation, the gas flow and the perforated plate airflow were kept constant. The premix air was adjusted to give the proper flame temperature and heating rate.

The insertion door operates a microswitch that marks the opening and closing on the recorder chart. The door also operates a lever mechanism that moves a chromel-alumel thermocouple into contact with the unexposed (backface) side of the test specimen.

TEST PROCEDURE

The tester was brought to the proper operating conditions with the specimen insertion door closed, with the flame baffle in position in the test specimen window (shown in this position in figure 8), and with a previously weighed glass wool filter in place in the wire tray shown at the top of the chimney. The test specimen, conditioned as described previously, was weighed and placed into a picture frame holder. The recorder chart was started. The door was opened and the test specimen was inserted, pushing the baffle out of a slot in the opposite wall. The door was closed. The outputs from the flame temperature thermocouple, the backface temperature thermocouple, and the exhaust gas temperature thermocouple were continuously drawn on the recorder chart throughout the test.

## A.5 SMOKE AND TOXIC GAS GENERATION

Smoke and toxic gas generation were determined in an accumulating chamber of the design used by the National Bureau of Standards and described in the NBS Technical Note 708, "Interlaboratory Evaluation of Smoke Density Chamber," December 1971. The test equipment and operation are described in the following paragraphs.

TEST CHAMBER

The test chamber is a sealed metal box 0.9 m (3 ft) wide by 0.61 m (2 ft) long by 0.9 m (3 ft) high with a total capacity of 0.51 $m^3$ (18 $ft^3$).

The test chamber contains a furnace, specimen holder, and photometer system and has provision for the attachment of a gas burner. The chamber is shown in figure 9.

PHOTOMETRIC SYSTEM

The photometric system consists of a high-intensity light source and photocell. The light path is vertical within the chamber in order to reduce errors arising from smoke stratification. A sensitive amplifier with large meter scales for accurate readings is supplied as the readout system, and by this means values of light transmittance are obtained. A recorder is connected to the meter so that a continuous plot of transmittance is obtained.

The percentage change in the light transmission is converted to an optical density value by means of the following equation:

$$D_s = \frac{V}{AL} \log_{10}\left(\frac{100}{T}\right)$$

where:

$D_s$ = optical density
$V$ = chamber volume, 0.51 $m^3$ (18 $ft^3$)
$L$ = light path length, 0.91 m (3 ft)
$A$ = exposed test specimen surface area, 100.8 $cm^3$ (15.63 $in^2$)
$T$ = % transmission

## TESTING PROCEDURE

The test specimen size was 7.62 x 7.62 cm (3 x 3 in.). The back, edges, and unexposed front surface of the specimen were covered by a single sheet of aluminum foil. The foil-protected specimens were then backed by a 7.62- x 7.62- x 1.27-cm (3- x 3- x 0.5-in.) sheet of asbestos millboard. The use of asbestos sheet minimizes the heat loss through the rear of the specimen. The microjet gas burner was placed in front of the radiant furnace so that the jets impinged on the bottom surface of the specimen. The air/propane mixture was adjusted to the correct ratio and flow rate by the adjustment of two independent flowmeters. The specimen was then slid across into the heat path of the furnace and in front of the gas jets, and burning commenced. After completion of each test, the cabinet was vented and the photocell cleaned. At least four specimens were tested from each panel.

## RADIANT HEAT FURNACE

The specimen under test is irradiated by means of an electrically heated radiant energy source mounted within an insulated ceramic tube, positioned so that an irradiance level of 2.5 $W \cdot cm^{-2}$ averages over the central 3.81-cm (1.5-in.) diameter area of the vertically mounted specimen. The irradiance level is determined by the applied voltage to the furnace, which is controlled by a rheostat.

## GAS BURNER

The gas burner has six flamelets, three of which are directed horizontally at right angles to the sample surface; three are canted downward to impinge normally on the specimen surface.

## SPECIMEN HOLDERS

The specimen holders, fabricated from stainless steel, are designed to expose a 6.51-cm (2.562-in.) square specimen area to the radiant heat of the furnace. The gas jets emerge along the bottom edge of the specimen. The specimen, supported as previously described, is located vertically, 3.81 cm (1.5 in.) front of the furnace opening. A 7.62-cm (3-in.) square of asbestos millboard is used to back the specimen, and the whole assembly is retained by a bent spring of phosphor bronze sheet and a steel retaining rod.

Toxic gas generation was determined quantitatively by means of four colorimetric tubes (Draeger) tubes mounted centrally in the test chamber during the smoke test runs. Each tube was designed by the manufacturer (Dräeger) to measure a specific type of gaseous product. The gases measured were cyanide (HCN), chlouride (HCl), bromide (HBr), and sulfur oxides ($SO_2$, $SO_3$).

Figure 9 is a photograph of the test chamber. Typical data plots are shown in figures 36 and 37.

### A.6. LIMITING OXYGEN INDEX (LOI)

Limiting oxygen index tests were determined in the oxygen-nitrogen test apparatus shown in figure 10. The tests were conducted in conformance with ASTM D2863T.

The method of operation was to select the initial concentration of oxygen based on past experience with similar materials. The gas was allowed to flow for 30 sec to purge the system. The specimen was ignited so that the entire tip was burning. The relative flammability was determined by adjusting the concentration of gases rising past the specimen to a point where the oxygen concentration was at the minimum that would allow the specimen to burn. Volumetric flow of the oxygen and nitrogen gases was measured by calibrated glass flow meters. The oxygen index was calculated by the following formula:

$$n(\%) = \frac{100 \times O_2}{O_2 + N_2}$$

where $O_2$ and $N_2$ are the volumetric flow ($cm^3/sec$).

The specimens were 150 mm (6 in) long by 6.5 ±0.5 mm (0.26 ±0.01 in.) wide and 3.0 ±0.5 mm (0.125 ±0.01 in.) thick. Since it was impractical to slice the sandwich to these dimensions, the face sheet, face sheet plus adhesive, and the core were tested separately.

### A.7. ENVIRONMENTAL EXPOSURE TESTS

#### CONDENSING HUMIDITY

The tests were performed in a Precision Scientific humidity cabinet operated at 49° ±1.1°C (120° ±2°F) and 95% to 100% relative humidity in conformance with Federal Test Method Std. 141a, Method 6062. The test specimens were 7.62 cm (3 in.) wide by 33 cm (13 in.) long. They were weighted on an analytical balance before and after exposure and the weight gain was calculated. The test specimens were then fabricated into peel test and flatwise tensile test specimens and tested. At least five specimens cut from each direction (longitudinal and transverse) of the panel were exposed.

#### DISTILLED WATER IMMERSION

The tests were performed in a stainless steel covered water bath maintained at 21°C (70°F) to 26°C (78°F). The specimens were supported on blocks of wood so that the specimen surfaces were covered by water to a depth of 2.54 cm (1 in.). The test specimens were 7.62 cm

(3 in.) wide by 33 cm (13 in.) long. They were weighed on an analytical balance before and after exposure, and the weight gain was calculated. The test specimens were then fabricated into peel test and flatwise tensile test specimens and tested as described in ASTM Test Method C365-57. At least five specimens cut from each direction (longitudinal and transverse) of the panel were tested.

## SALT SPRAY

The tests were performed in a salt spray chamber maintained at 35° (+1.1°C, -1.7°C) [95° (+2°F, -3°F)]. The solution was a 5% salt solution, ph 6.5 to ph 7.2. The specimens were 5.08 cm (2 in.) by 5.08 cm (2 in.) by the panel thickness. The specimens were examined at 10X magnitication under a wide field microscope before and after exposure. Representative test specimens from each of the panel sets were photographed at 10X magnification before and after exposure. At least five specimens per panel were exposed.

*Table 1.—Panel Constructions*

| Panel | Identification | Face sheets | Adhesive | Core |
|---|---|---|---|---|
| 1 | Boeing | [a]Narmco 8250-7581 | Narmco 9250-112 | HRH-10, 1/8-in. cell, NOMEX[R], 5.0 lb/ft$^3$ |
| 2 | Boeing | Deco XMP 100, phenolic[b] | Narmco 9250-112 | HRH-10, 1/8-in. cell, NOMEX[R], 5.0 lb/ft$^3$ |
| 3 | Boeing | DuPont 7781-PG 003, polyimide[a] | American Cyanamid BR-34B-18 polyimide | HRH-310, 1/8-in. cell, NOMEX[R], 5.0 lb/ft$^3$ |
| 4 | Boeing | DuPont 7781 PG 003, polyimide | American Cyanamid BR-34B-18 polyimide | HRH-310, 1/8-in. cell, NOMEX[R], 5.0 lb/ft$^3$ with urea-formaldehyde foam (Rapco) fill |
| 5 | Boeing | [a,d]Narmco 8250 | Narmco 9251-112 | HRH-10, 1/8-in. cell, NOMEX[R], 5.0 lb/ft$^3$ |
| 6 | General Veneer | Geneerco LS, phenolic[b] | Undefined epoxy | HRH-10, 1/8-in. cell, NOMEX[R], 9.0 lb/ft$^3$ |
| 7 | Panel Air | [b]Deco XMP 20 | Narmco 1133, 0.032 lb/ft$^2$ | HRH-10, 1/8-in. cell, 5.0 PCF |
| 9 | Ciba-Geigy | Ciba DLS 431-1581, phenolic | Ciba DLS 421, phenolic | HRH-10, 1/8-in. cell, 5.0 lb/ft$^3$ NOMEX[R], foam-filled |
| 10 | Northrop-Pacific | Deco XMP 100 | Not stated | HRH-10, 1/8-in. cell, NOMEX[R], 5.0 lb/ft$^3$ |
| 12 | NASA | Aluminum foil, one face | — | Sablon fiber reinforced foam |
| 13 | Ciba-Geigy | Ciba epoxy[b] | Ciba epoxy | HRH-10, 1/8-in. cell, NOMEX[R], 5.0 lb/ft$^3$ |
| 14 | Ciba-Geigy | Ciba epoxy[b] | Ciba epoxy | HRH-10, 1/8-in. cell, NOMEX[R], 9.0 lb/ft$^3$ |
| 15 | General Veneer | Geneerco epoxy[b] | Epoxy | HRH-10, 1/8-in. cell, NOMEX[R], 9.0 lb/ft$^3$ |
| 16 | Panel Air | Deco XMP 20, phenolic[b] | Narmco 1133, 0.060 lb/ft$^2$ | HRH-10, 1/8-in. cell, NOMEX[R], 5.0 lb/ft$^3$ |
| 17 | Panel Air | Deco XMP 100, phenolic[b] | Narmco 1133, 0.032 lb/ft$^2$ | HRH-10, 1/8-in. cell, NOMEX[R], 5.0 lb/ft$^3$ |
| 18 | Panel Air | Deco XMP 100, phenolic[b] | Narmco 1133, 0.060 lb/ft$^2$ | HRH-10, 1/8-in. cell, NOMEX[R], 5.0 lb/ft$^3$ |

[a]Two plies each face, 0° to 90° cross-plied

[b]Unidirectional glass reinforcement, 0° to 90° cross-plied, two plies each face

[c]Polyimide resin dipped core

[d]Narmco 8250 or Deco XMP 100 resin system received too late to test

*Table 1.—(Concluded)*

| Panel | Identification | Face sheets | Adhesive | Core |
|---|---|---|---|---|
| 19 | Ciba-Geigy | Phenolic-1581 woven glass[e] | Phenolic-120 | HRH-10, 1/8-in. cell, NOMEX[R], with phenolic foam (Ciba) fill |
| 20 | Ciba-Geigy | Phenolic-1581 woven glass[e] | Phenolic-120 | HRH-10, 1/8-in. cell, NOMEX[R], unfilled |
| 21 | Northrop-Pacific | Deco XMP 100, phenolic[b] | Not stated | HRH-10, 1/8-in. cell, NOMEX[R], 9 lb/ft$^3$, foam filled |
| 22 | Northrop-Pacific | NP LS, woven glass | Not stated | HRH-10, 1/8-in. cell, NOMEX[R], 9 lb/ft$^3$, unfilled |
| 23 | Panel Air | Panel air, low-smoke[b] | Narmco 1133, 0.035 lb/ft$^2$ | HRH-10, 1/8-in. cell, NOMEX[R], 5.0 lb/ft$^3$ |
| 24 | Panel Air | Panel air, low-smoke[b] | Narmco 1133, 0.060 lb/ft$^2$ | HRH-10, 1/8-in. cell, NOMEX[R], 5.0 lb/ft$^3$ |
| 25 | Gill Corp. | Integrally woven fluted core structure, phenolic | None | Woven structure, flute size 1/2 by 1 in. rectangle |
| 26 | General Veneer | Geneerco LS (Deco XMP 100) | Undefined epoxy | HRH-10, 1/8-in. cell, NOMEX[R], 5.0 lb/ft$^3$ |

[b]Unidirectional glass reinforcement, 0° to 90° cross-plied, two plies each face

[e]Three plies top face, two plies bottom face

*Table 2.—Summary of Test Data*

| Panel | Identification and materials | Measurements: Weight kg/m$^2$ (lb/ft$^2$) | Measurements: Warpage, cm/m (in/ft) | Measurements: Thickness, cm (in.) | Impact tests, failure load, kg · m (in-lb) | FAR flame tests (1 60-sec burn test, max burn length, 15.2 cm (6 in.); 2 12-sec burn test, max burn length, 20.3 cm (8 in.)): Extinguishment time, sec 1 | Extinguishment time, sec 2 | Burn length, cm (in.) 1 | Burn length, cm (in.) 2 | Burn-through tests: Pen[a] | Burn-through tests: Backface temp at 10 min, °C (°F) | Smoke and toxic gas generation tests: Optical density, Ds, at 1.5 min | Optical density, Ds, at 4 min | Optical density, Ds, at 4 to 20 min (max) | Fatigue—food cart roller tests: at 30-kg (67-lb) load, Survival, cycles x $10^3$ | at 44-kg (98-lb) load, Survival, cycles x $10^3$ | at 58-kg (128-lb) load, Survival, cycles x $10^3$ | Flexure tests: Failure load, kg (lb) | Flexure tests: Deflection at 45.3-kg (100-lb) load, cm (in.) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 13 | Ciba-Geigy, type 1 (underseat) | 2.37 (0.486) | <0.17 (0.02) | 1.01 (0.399) | 0.46 (40.0) | 1.1 | 0.0 | 12.95 (5.1) | 4.57 (1.8) | None[b] | 254.4 (490.0) | 165.0 | 171.0 | 175.0 | 120, no flr | 115, no flr | Failed at 0.05 | 109.2 (240 7) | 2.05 (0.807) |
| 14 | Ciba-Geigy, type 2 (aisle panel) | 2.98 (0.61) | | 1.041 (0 410) | 0.77 (67.0) | 2.6 | 0.0 | 11.68 (4.6) | 5 84 (2.3) | | 265.6 (510.0) | 116.0 | 154.0 | 154.0 | 120, no flr | 115, no flr | 125, no flr | 1.33 (294.0) | 1.67 (0.66) |
| 15 | General Veneer, type 2 (aisle panel) | 3.08 (0.63) | | 1.05 (0.414) | 0.41 (36.0) | 1.5 | 6.3 | 9.9 (3 9) | 6.6 (2.6) | | 404.0 (760 0) | 212.0 | 209 0 | 217.0 | 120, no flr | 115, no flr | 125, no flr | 140.6 (310 0) | |
| 1 | Boeing, 8250-7581, 9250-112 adh Narmco | 3 03 (0.62) | | 1.07 (0.420) | 0.17 (15.0) | 4.8 | 1.0 | 11.3 (4.45) | 4 57 (1.8) | | 382.0 (720.0) | 0.38 | 1.66 | 7.07 | — | 115, no flr | Failed at 3.4 | 202 8 (447.0) | 1.40 (0.55) |
| 3 | Boeing, polyimide, 7581 glass | 2.73 (0.56) | | 1.041 (0.410) | 0.17 (15.0) | 0.9 | 0.9 | 6 86 (2.7) | 0.76 (0.3) | | 365.6 (690.0) | 0.03 | 0.16 | 3.09 | — | Failed at <80 | | 149.6 (329.7) | |
| 4 | Boeing, PI-7581 glass-foam fill UFC (Rapco) foam 0.5 PCF | 3.10 (0.637) | | 1.092 (0.430) | 0.17 (15.0) | 0.9 | 0.9 | 6.86 (2.7) | 0.76 (0.3) | | 343.3 (650.0) | 0.49 | 2.06 | 15.3 | — | — | — | — | — |
| 6 | General Veneer, phenolic, unidirectional glass | 3.17 (0.65) | | 1.038 (0.409) | 0.68 (59.0) | 0.0 | 0.0 | 15.24 (6.0) | 7.11 (2 8) | | 422.0 (792.0) | 6.12 | 14.5 | 34.3 | — | — | — | — | — |
| 7 | Panel Air, phenolic, unidirectional glass, 0.032 adhesive | 2.88 (0.59) | | 1.01 (0 399) | 0.75 (65.0) | 15.0 | 17 8 | 8 51 (3.35) | 4.06 (1.6) | | 399.0 (750.0) | 3.25 | 5.09 | 11.7 | — | Failed at 16.0 | | 137.7 (303.5) | 1.64 (0.644) |
| 9 | Ciba-Geigy, DLS 431-1581 GI | 3.71 (0.76) | | 1.041 (0.410) | — | — | — | — | — | | — | 2.53 | 18.0 | 24.6 | — | — | — | — | — |
| 10 | Northrop-Pacific, phenolic, unidirectional glass | 3.17 (0.65) | | 1.036 (0.408) | 0 40 (35.0) | 2.8 | 0.0 | 16 51 (6.5) | 6.6 (2.6) | | 435.0 (815.0) | 3.45 | 8 77 | 25.1 | — | — | — | — | — |
| 16 | Panel Air, phenolic unidirectional glass, 0.060 adhesive | 2.78 (0.57) | | 1.01 (0.398) | 0.71 (62.07) | 25.5 | 56.6 | 8.76 (13.45) | 6.1 (2.4) | | 393.0 (740.0) | 1.97 | 3.92 | 10.0 | — | Failed at 11.7 | — | — | — |
| 17 | Panel Air, phenolic, unidirectional glass, 0.032 adhesive | 2.78 (0.57) | | 1.016 (0.400) | 1.18 (102.0) | 10.4 | 32 5 | 6.73 (2.65) | 3.43 (1.35) | | 354.0 (670.0) | 5.43 | 9.26 | 24.0 | — | Failed at 113 | — | 145.5 (320.7) | 1.66 (0.653) |
| 18 | Panel Air, phenolic, unidirectional glass, 0.60 adhesive | 3.17 (0.65) | | 1.046 (0.412) | 1.09 (95.0) | 39.5 | 68.2 | 9.65 (3.8) | 4.06 (1.6) | | 354.0 (670.0) | 5.40 | 10.5 | 14.6 | — | Failed at 113 | — | 146.0 (321.8) | 1.67 (0.658) |
| 19 | Ciba-Geigy, DLS 438-1581 glass | 4.2 (0.86) | | 1.092 (0.430) | 0.47 (41.0) | 8.0 | 1.0 | 8.13 (3.2) | 1.4 (0.55) | | 316.0 (600.0) | 1.34 | 25.7 | 43.0 | — | 119.5 no flr | Failed at 116.5 | 109.9 (242.3) | 1.31 (0.515) |
| 20 | Ciba-Geigy, DLS 438-1581 glass (foam-filled core) | 4.59 (0.94) | | 1.092 (0.430) | 0.53 (46.0) | 9.4 | 1.1 | 8.76 (3.45) | 1.14 (0.45) | | 265.6 (510.0) | 3.67 | 14.5 | 17.3 | — | Failed at 83.4 | — | 101.1 (223.0) | 1.54 (0.605) |
| 21 | Northrop-Pacific, phenolic, unidirectional glass | 3.27 (0.67) | | 1.061 (0.418) | 0.71 (62.0) | 8.6 | 1.9 | 7.49 (2.95) | 2.29 (0.9) | | 382.0 (720 0) | 5.66 | 11.4 | 38.1 | — | Failed at 112 | — | 196.9 (434.0) | 1.4 (0.55) |
| 22 | Northrop-Pacific, LS, woven glass | 3 27 (0 67) | | | 0.37 (32.0) | 26.9 | 1.1 | 11.68 (4.6) | 6.86 (2.7) | | 354.0 (670.0) | 253.0 | 257.0 | 264.0 | — | — | — | 114.9 (253.4) | 1.96 (0.77) |
| 23 | Panel Air, phenolic, unidirectional glass, 0 032 adhesive | 2.83 (0 58) | | 1.08 (0.426) | 0.62 (54.0) | 16.4 | 12.6 | 11.4 (4 5) | 4.19 (1.65) | | 360.0 (680.0) | 10 9 | 16.5 | 23.7 | — | 122.4 no flr | Failed at 26.8 | 143.9 (317.3) | 1.74 (0.685) |
| 24 | Panel Air, phenolic, unidirectional glass, 0.060 adhesive | 2 88 (0.59) | | 1.074 (0.423) | 0.61 (53 0) | 40.4 | 58.2 | 10.92 (4.3) | 3.56 (1.4) | | 348.9 (660.0) | 30.5 | 34.7 | 42.0 | — | Failed at 31 | | 154.9 (341.5) | 1.70 (0 67) |
| 25 | Gill Corp., phenolic integrally woven structure | 2.94 (0.603) | | 1.244 (0.490) | 0.17 (15.0) | 1.8 | 1.7 | 11.68 (4.6) | 6.6 (2.6) | | 458.3 (857.0) | 3.54 | 9.79 | 32.6 | — | — | — | 107.0L (236.0) 69.4T (153.0) | 1.32 (0.52) 1.85 (0.72) |
| 26 | General Veneer, phenolic, unidirectional glass | 2.65 (0.543) | <0.17 (0.02) | 1.074 (0.423) | 0.66 (57.0) | 3.8 | 1.6 | 6.1 (2.4) | 3.68 (1.45) | None[b] | 433.9 (813.0) | 4.72 | 6.20 | 26.4 | — | Failed at 115.4 | — | 158.5 (349.4) | 1.99 (0.785) |
| | Program requirements | 3.4 (0.70) max | 0.21 (0.025) max | No reqt | 0.35 (30.0) min | 15.0 | 15.0 | 15.2 (6.0) | 20.3 (8.0) | No penetration of front face | | $D_s$, 75 maximum | | | 115 min | 115 min | None | 90.7 (200.0) min | 2.03 (0.80) |

[a]Penetration

[b]Front face resin burned completely away

[c]Front face separated from core early in test period

A.

B

*Table 3.—FAR 25-32 Flame Tests*

| Panel | Identification | Extinguishment time, sec | | | | | | Burn length, cm (in ) | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | 60-sec burn test | | | 12-sec burn test | | | 60-sec burn test | | | 12-sec burn test | | |
| | | Spec 1 | Spec 2 | Average | Spec 1 | Spec 2 | Average | Spec 1 | Spec 2 | Average | Spec 1 | Spec 2 | Average |
| 13 | Ciba-Geigy, type 1 | 0 0 | 2.2 | 1 1 | 0.0 | 0 0 | 0 0 | 10 92 (4 3) | 14 98 (5.9) | 12.95 (5.1) | 3.05 (1.2) | 6.1 (2.4) | 4.57 (1 8) |
| 14 | Ciba-Geigy, type 2 | 2 3 | 2 8 | 2.6 | 0 0 | 0.0 | 0.0 | 11 43 (4.5) | 11 94 (4.7) | 11 68 (4.6) | 5 59 (2.2) | 5 84 (2.3) | 5.84 (2.3) |
| 1 | Boeing | 6.3 | 3.3 | 4.8 | 1.0 | 1.0 | 1.0 | 10.92 (4 3) | 11.68 (4 6) | 11.3 (4.45) | 4.57 (1.8) | 4.57 (1.8) | 4.57 (1.8) |
| 3 | Boeing | 0.9 | 0.9 | 0.9 | 0 9 | 0.9 | 0.9 | 6 86 (2 7) | 6.86 (2.7) | 6 86 (2.7) | 0 76 (0.3) | 0.76 (0.3) | 0 76 (0.3) |
| 4 | Boeing | – | – | – | – | – | – | – | – | – | – | – | – |
| 6 | General Veneer | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 17.78 (7.0) | 12.7 (5.0) | 15.24 (6.0) | 7.37 (2.9) | 6.86 (2.7) | 7.11 (2.8) |
| 7 | Panel Air | 14.2 | 15.7 | 15.0 | 13.7 | 21.8 | 17 8 | 8.38 (3.3) | 8.64 (3.4) | 8.51 (3.35) | 2.29 (0.9) | 5.84 (2.3) | 4.06 (1.6) |
| 9 | Ciba-Geigy | – | – | – | – | – | – | – | – | – | – | – | – |
| 10 | Northrop-Pacific | 0.0 | 5.5 | 2.8 | 0.0 | 0.0 | 0.0 | 20.06 (7.9) | 12.95 (5.1) | 16.51 (6.5) | 4.83 (1.9) | 8.13 (3.2) | 6.6 (2.6) |
| 16 | Panel Air | 25.6 | 25 5 | 25.5 | 57.6 | 55.6 | 56.6 | 9 14 (3 6) | 8.38 (3.3) | 8.76 (3.45) | 5.84 (2.3) | 6.1 (2.4) | 6.1 (2.4) |
| 17 | Panel Air | 6 0 | 14.7 | 10.4 | 28 5 | 36 5 | 32.5 | 6.1 (2.4) | 7.37 (2.9) | 6.73 (2.65) | 3.3 (1.3) | 3.56 (1.4) | 3.43 (1.35) |
| 18 | Panel Air | 46.2 | 32 7 | 39 5 | 74.1 | 62.3 | 68 2 | 9.4 (3.7) | 9.91 (3.9) | 9 65 (3.8) | 4.06 (1.6) | 4.06 (1.6) | 4.06 (1.6) |
| 19 | Ciba-Geigy | 6.9 | 9.0 | 8.0 | 1.0 | 1.0 | 1.0 | 8.38 (3 3) | 7.87 (3.1) | 8.13 (3.2) | 1.27 (0.5) | 1.52 (0.6) | 1 4 (0.55) |
| 20 | Ciba-Geigy | 12.5 | 6.3 | 9 4 | 1.0 | 1.2 | 1.1 | 8.89 (3.5) | 8.64 (3.4) | 8.76 (3.45) | 1.02 (0.4) | 1.27 (0.5) | 1.14 (0.45) |
| 21 | Northrop-Pacific | 7.4 | 9.8 | 8.6 | 1.6 | 2.2 | 1.9 | 7.37 (2.9) | 7.62 (3.0) | 7.49 (2.95) | 2.29 (0.9) | 2.29 (0.9) | 2.29 (0.9) |
| 22 | Northrop-Pacific, LS | 25.9 | 27.8 | 26.9 | 1.0 | 1.2 | 1.1 | 9.65 (3.8) | 13.46 (5.3) | 11.68 (4.6) | 6.35 (2.5) | 7.11 (2.8) | 6.86 (2.7) |
| 23 | Panel Air, LS | 16.9 | 15.9 | 16 4 | 10.8 | 14.4 | 12.6 | 11.68 (4 6) | 11.18 (4 4) | 11.4 (4.5) | 4.83 (1.9) | 3 56 (1.4) | 4.19 (1.65) |
| 24 | Panel Air, LS | 39.7 | 41.0 | 40 4 | 63.5 | 53.0 | 58 2 | 11.18 (4.4) | 10.67 (4.2) | 10.92 (4.3) | 4.57 (1.8) | 2.54 (1.0) | 3.56 (1.4) |
| 25 | Gill Corp. | 2.2 | 1.4 | 1.8 | 1.9 | 1.4 | 1.7 | 11.94 (4 7) | 11.43 (4 5) | 11.68 (4 6) | 6.86 (2.7) | 6.35 (2.5) | 6.6 (2.6) |
| 26 | General Veneer | 4.2 | 3.4 | 3 8 | 1.3 | 1.9 | 1.6 | 5 84 (2 3) | 6.35 (2 5) | 6.1 (2 4) | 3.3 (1.3) | 4.06 (1.6) | 3.68 (1.45) |

*Table 4.—Burn-Through Tests*

| Panel | Identification | Max heat contribution Btu/min, per 19 in.$^2$ | | Weight loss, gm per 19 in.$^2$ after 10 min | |
|---|---|---|---|---|---|
| | | Spec 1 | Spec 2 | Spec 1 | Spec 2 |
| 13 | Ciba-Geigy, type 1 | 13.0 | 9.8 | 4.1818 | 3.1390 |
| 14 | Ciba-Geigy, type 2 | 13.0 | | 5.4124 | 5.7784 |
| 1 | Boeing | 4.2 | 5.8 | 5.3321 | 4.7630 |
| 3 | Boeing | 9.75 | 4.2 | 3.2668 | 3.0844 |
| 4 | Boeing | 1.7 | 1.2 | 5.1381 | 5.5149 |
| 6 q | General Veneer | 1.75 | 2.4 | 7.4948 | 8.0863 |
| 7 | Panel Air | — | — | — | — |
| 9 | Ciba-Geigy | — | — | — | — |
| 10 | Northrop-Pacific | 10.3 | 1.8 | 7.5554 | 6.9478 |
| 16 | Panel Air | 1.75 | 12.05 | 7.9669 | 4.0187 |
| 17 | Panel Air | 14.5<br>13.0 | 14.7<br>11.8 | 6.5077<br>6.0998 | 5.6766<br>5.7559 |
| 18 | Panel Air | 14.0 | 38.0 | 8.1515 | 7.3325 |
| 19 | Ciba-Geigy | 14.0 | 15.6 | 7.3572 | 7.3072 |
| 20 | Ciba-Geigy | 26.0 | 15.6 | 6.7056 | 6.6507 |
| 21 | Northrop-Pacific | — | — | 6.3349 | 5.8266 |
| 22 | Northrop-Pacific, LS | 30.0 | 29.0 | 9.1049 | 9.4672 |
| 23 | Panel Air, LS | 2.6 | 5.2 | 4.7362 | 5.5337 |
| 24 | Panel Air, LS | 8.2 | 17.6 | 6.3072 | 5.8890 |
| 25 | Gill Corp. | — | — | — | — |
| 26 | General Veneer | — | — | 4.7966 | 5.2740 |

*Table 5.—Limiting Oxygen Index*

| Panel | Identification | Oxygen required to sustain burn, % | |
|---|---|---|---|
| | | Face plus adhesive | Face only |
| 13 | Ciba-Geigy, type 1 | | |
| 14 | Ciba-Geigy, type 2 | 36.0 | 36.89 |
| 1 | Boeing | 52.0 | 54.0 |
| 21 | Northrop-Pacific | 36.89 | 100.0 |
| 23 | Panel Air, LS | 30.63 | 39.5 |
| 26 | General Veneer | 35.89 | 100.0 |

*Table 6.—Flexure Tests*

| Panel | Identification | Ultimate load, kg (lb) | Average load, kg (lb) | Deflection under 45.3-kg (100-lb) load, cm (in.) |
|---|---|---|---|---|
| 13 | Ciba-Geigy, type 1 | 124.7 (275.0) 104.3 (230.0)<br>98.4 (217.0) | 109.2 (240.7) | 2.29 (0.90) 1.93 (0.76)<br>1.93 (0.76) |
| 14 | Ciba-Geigy, type 2 | 135.3 (298.2) 127.0 (280.0)<br>132.7 (292.6) 133.0 (293.3)<br>122 9 (270.9) | 130.2 (287.0) | 1.70 (0.67) 1.65 (0.65)<br>1.65 (0.65) 1 70 (0.67)<br>1.68 (0.66) |
| 1 | Boeing | 193.7 (427.0) 201.9 (445.2)<br>208.3 (459.2) 207.0 (456.4) | 202.8 (447.0) | 1.42 (0.56) 1.40 (0 55)<br>1.37 (0.54) 1.40 (0.55) |
| 3 | Boeing | 141.6 (312.2) 159.1 (350.7)<br>151.5 (334.0) 146.0 (322.0) | 149.6 (329.7) | 1.60 (0.63) 1.60 (0.63)<br>1.55 (0.61) 1.70 (0.67) |
| 4 | Boeing | — — | — | — — |
| 6 | General Veneer | — — | — | — — |
| 7 | Panel Air | 148.3 (327.0) 142.6 (314.3)<br>134.6 (296.8) 148.8 (327.0)<br>114.6 (252.7) | 137.7 (303.5) | 1.65 (0.65) 1.65 (0.65)<br>1.55 (0.61) 1.55 (0.61)<br>1.65 (0.65) |
| 9 | Ciba-Geigy | — — | — | — — |
| 10 | Northrop-Pacific | — — | — | — — |
| 16 | Panel Air | — — | — | — — |
| 17 | Panel Air | 140.0 (308.7) 149.2 (329.0)<br>141.5 (312.0) 151.1 (333.2) | 145.5 (320.7) | 1.60 (0.63) 1.68 (0.66)<br>1.68 (0.66) 1.68 (0.66) |
| 18 | Panel Air | 121.0 (266 7) 148.0 (326.2)<br>158.1 (348.6) 156.9 (345.8) | 146.0 (321 8) | 1.70 (0.67) 1.65 (0.65)<br>1.65 (0.65) 1.68 (0.66) |
| 19 | Ciba-Geigy | 108.6 (239.5) 111 0 (245.0) | 109.8 (242.0) | 1.32 (0.52) 1.29 (0.51) |
| 20 | Ciba-Geigy | 102.0 (225.0) 100.0 (221.0) | 101.1 (223.0) | 1.57 (0.62) 1.50 (0.59) |
| 21 | Northrop-Pacific | 202.6 (446.6) 187.0 (412.3)<br>200.7 (442.4) 197.5 (435.4) | 196.9 (434.0) | 1.40 (0.55) 1.40 (0.55)<br>1.40 (0.55) 1.40 (0.55) |
| 22 | Northrop-Pacific, LS | 124.1 (273.7) 128.0 (282.5)<br>129.2 (284.9) 77.8 (171.5) | 114.9 (253.4) | 1.91 (0.75) 1.91 (0.75)<br>2.00 (0.79) 2.00 (0.79) |
| 23 | Panel Air, LS | 145.8 (321.5) 152.2 (335.5)<br>134.7 (297.0) 142.9 (315.0) | 143.8 (317.0) | 1.65 (0.65) 1.73 (0.68)<br>1.78 (0.70) 1.80 (0.71) |
| 24 | Panel Air, LS | 162.1 (357.5) 150.6 (332.0)<br>164.0 (361.5) 142.9 (315.0) | 154.7 (341.0) | 1.68 (0.66) 1.73 (0.68)<br>1.70 (0.67) 1.70 (0.67) |
| 25 | Gill Corp. | 105.2 (232.0) 108.9 (240.0) | | 1.35 (0.53) 1.29 (0.51)<br>1.83 (0.72) 1.88 (0.74) |
| 26 | General Veneer | 153.3 (338.0) 160.3 (353.5)<br>155.8 (343.5) 164.4 (362.5) | 158.3 (349.0) | 1.63 (0.64) 1.57 (0.62)<br>1.60 (0.63) 1.55 (0.61) |

*Table 7.—Environmental Exposure Tests*

| Panel | Identification | Flatwise tensile strength, kg/cm$^2$ (psi) | Specimen weight, gm | | Wt gain average, percent |
|---|---|---|---|---|---|
| | | | Before exposure | After exposure | |
| | | *No Exposure* | | | |
| 14 | Ciba-Geigy, type 2 | 46.22 (657.5) | | | |
| | | 43.41 (617.5) | | | |
| | | 51.67 (735.0) | | | |
| | | 44.99 (640.0) | | | |
| 21 | Northrop-Pacific | 40.07 (570.0) | | | |
| | | 35.15 (500.0) | | | |
| | | 48.33 (687.5) | | | |
| | | 43.94 (625.0) | | | |
| | | 56.42 (802.5) | | | |
| 23 | Panel Air, LS | 27.24 (387.5) | | | |
| | | 37.80 (495.0) | | | |
| | | 31.46 (447.5) | | | |
| | | 33.04 (470.0) | | | |
| | | 35.33 (502.5) | | | |
| 26 | General Veneer | 40.77 (580.0) | | | |
| | | 40.60 (577.5) | | | |
| | | 36.38 (517.5) | | | |
| | | 36.38 (517.5) | | | |
| | | *After 14 Days in Condensing Humidity Chamber* | | | |
| 14 | Ciba-Geigy, type 2 | 44.11 (627.5) | 72.5 | 75.5 | 5.06 |
| | | 42.36 (602.5) | 75.5 | 79.5 | |
| | | 43.23 (615.0) | 73.5 | 77.8 | |
| | | 40.78 (580.0) | 74.5 | 78.5 | |
| | | 45.52 (647.5) | | | |
| 21 | Northrop-Pacific | 31.46 (447.5) | 68.5 | 72.0 | 6.22 |
| | | 36.20 (515.0) | 83.0 | 93.5 | |
| | | 36.91 (525.0) | 83.0 | 86.5 | |
| | | 30.58 (435.0) | 84.0 | 89.5 | |
| | | 33.92 (482.5) | 84.0 | 88.5 | |
| | | | 70.5 | 75.0 | |
| 23 | Panel Air, LS | 28.30 (402.5) | 71.5 | 80.0 | 10.59 |
| | | 26.36 (375.0) | 70.0 | 81.0 | |
| | | 27.94 (397.5) | 71.5 | 79.0 | |
| | | 27.94 (397.5) | 72.0 | 79.5 | |
| | | 25.31 (360.0) | 72.0 | 79.5 | |
| | | | 73.5 | 82.0 | |
| 26 | General Veneer | 29.31 (417.5) | 61.0 | 65.0 | 11.5 |
| | | 41.83 (595.0) | 64.0 | 74.5 | |
| | | 41.30 (587.5) | | | |
| | | 42.18 (600.0) | | | |
| | | 40.25 (572.5) | | | |

*Table 7.—(Concluded)*

| Panel | Identification | Flatwise tensile strength, $kg/cm^2$ (psi) | Specimen weight, gm Before exposure | After exposure | Wt gain average, percent |
|---|---|---|---|---|---|
| *After 14 Days in Distilled Water* | | | | | |
| 14 | Ciba-Geigy, type 2 | 44.99 (640.0) | 72.0 | 74.0 | 3.79 |
| | | 46.22 (657.5) | 73.0 | 76.5 | |
| | | 49.21 (700.0) | | | |
| | | 32.16 (457.5) | | | |
| | | 47.10 (670.0) | | | |
| 21 | Northrop-Pacific | 52.55 (747.5) | 81.5 | 86.5 | 5.79 |
| | | 49.39 (702.5) | 83.0 | 88.0 | |
| | | 31.99 (455.0) | 70.5 | 75.0 | |
| | | 46.93 (667.5) | 83.5 | 88.0 | |
| | | 48.16 (685.0) | 84.0 | 89.5 | |
| | | | 69.0 | 72.0 | |
| 23 | Panel Air, LS | 25.48 (362.5) | 71.5 | 75.0 | 5.92 |
| | | 26.71 (380.0) | 68.5 | 73.5 | |
| | | 26.89 (382.5) | 73.5 | 79.0 | |
| | | 27.77 (395.0) | 72.0 | 76.0 | |
| | | 27.41 (390.0) | | | |
| 26 | General Veneer | 41.12 (585.0) | 63.5 | 67.5 | 6.09 |
| | | 41.83 (595.0) | 60.0 | 64.0 | |
| | | 41.3 (587.5) | | | |
| | | 42.18 (600.0) | | | |
| | | 40.25 (572.5) | | | |

*Table 8.—Thermogravimetric Test Data*

| Event | Panel number 14 | 21 | 23 | 26 |
|---|---|---|---|---|
| Weight loss began, °C (°F) | 225.0 (437.0) | 435.0 (815.0) | 310.0 (590.0) | 452.0 (846.5) |
| 1% weight loss | 312.0 (593.0) | 476.0 (888.0) | 312.0 (593.0) | 490.0 (914.0) |
| Weight loss rate maximum, °C (°F) | 315.0 (599.0) | 577.5 (1071.5) | 605.0 (1121.0) | 563.0 (1044.0) |
| 10% weight loss | 402.0 (755.0) | 586.0 (1086.0) | 455.0 (851.0) | 576.3 (1037.0) |
| Weight loss ceased, °C (°F) | 552.6 (1098.0) | 650.0 (1202.0) | 657.5 (1215.5) | 652.5 (1206.5) |
| % weight loss, final | 17.6 | 23.3 | 41.8 | 23.1 |

*Table 9.—Verification Test Data*

| Test | Requirement | General Veneer Panel 26 | Northrop Panel 21 |
|---|---|---|---|
| Weight, $kg/m^2$ ($lb/ft^2$) | 3.4 (0.70) | 2.65 (0.543) | 3.27 (0.67) |
| Warpage, $cm/m^2$ ($in/ft^2$) | <0.21 (0.025) | <0.17 (0.02) | <0.17 (0.02) |
| Thickness, cm (in.) | No requirement | 1.074 (0.423) | 1.061 (0.418) |
| Impact tests, failure load, kg • m (in-lb) | 0.35 (30) | 0.66 (57) | 0.71 (62) |
| FAR flame tests | | | |
| Extinguishment time, sec | | | |
| 1 60-sec burn test | 15 max | 3.8 | 8.9 |
| 2 12-sec burn test | 15 max | 2.4 | 1.9 |
| Burn length, cm (in.) | | | |
| 1 60-sec burn test | 15.2 (6.0) max | 4.06 (1.6) | 7.62 (3.0) |
| 2 12-sec burn test | 20.3 (8.0) max | 3.81 (1.5) | 2.29 (0.9) |
| Burn-through tests (backface temp at 10 min), °C (°F) | None | 434 (813) | 382 (720) |
| Smoke and toxic gas teneration tests, optical density, $D_s$, at | | | |
| 1.5 min | — | 4.72 | 5.66 |
| 4.0 min | — | 6.20 | 11.4 |
| 4 to 20 min (max) | 50 to 75 | 26.4 | 38.1 |
| LOI, percent | | | |
| Face sheet | 39 minimum | 100 | 100 |
| Face plus adhesive | for the total | 35.89 | 36.89 |
| Core | sandwith system | 33 | 33 |
| Fatigue, food cart roller tests, cycles (under 44-kg (98-lb) load) | 115 000 | 115 400 | 112 000 |
| Flexure tests, failure load, kg (lb) | 90.7 (200) | 158.5 (349.4) | 196.9 (434) |
| Environmental exposure tests | | | |
| Weight gain, percent | | | |
| Condensing humidity tests | 6 (after 14 days exposure) | 10.1 | 6.22 |
| Distilled water immersion | 6 (after 14 days exposure) | 6.09 | 5.79 |
| Flatwise tensile strength, $kg/cm^2$ (psi) | | | |
| No conditioning | None | 40.3 (573) | 44.8 (637) |
| 14 days' condensed humidity | None | 29.03 (413.5) | 33.8 (481) |
| 14 days' distilled water | None | 41.3 (588) | 45.8 (651.5) |

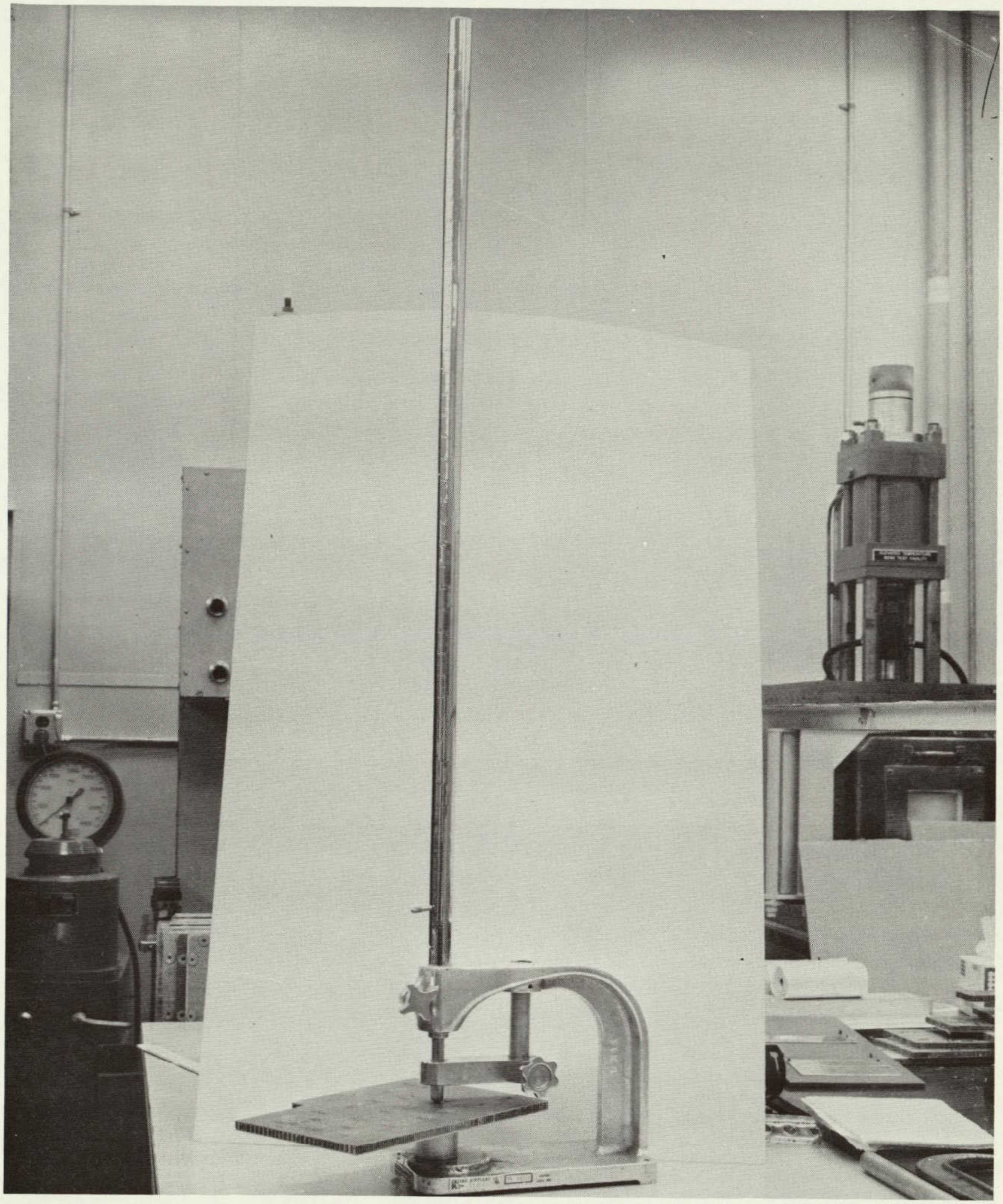


*Figure 1.—Gardener Impact Test Fixture*

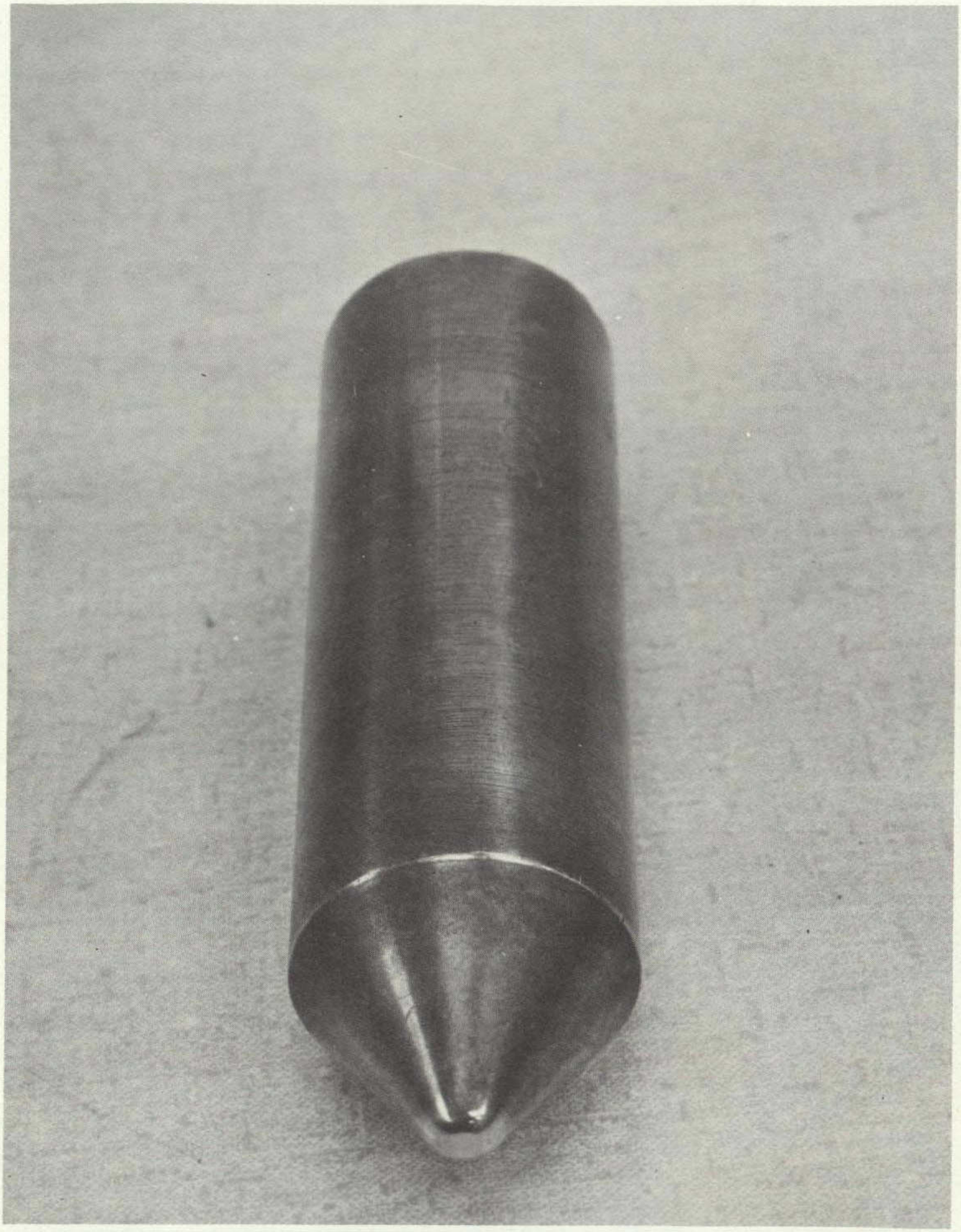


*Figure 2.—Impact Test Point*

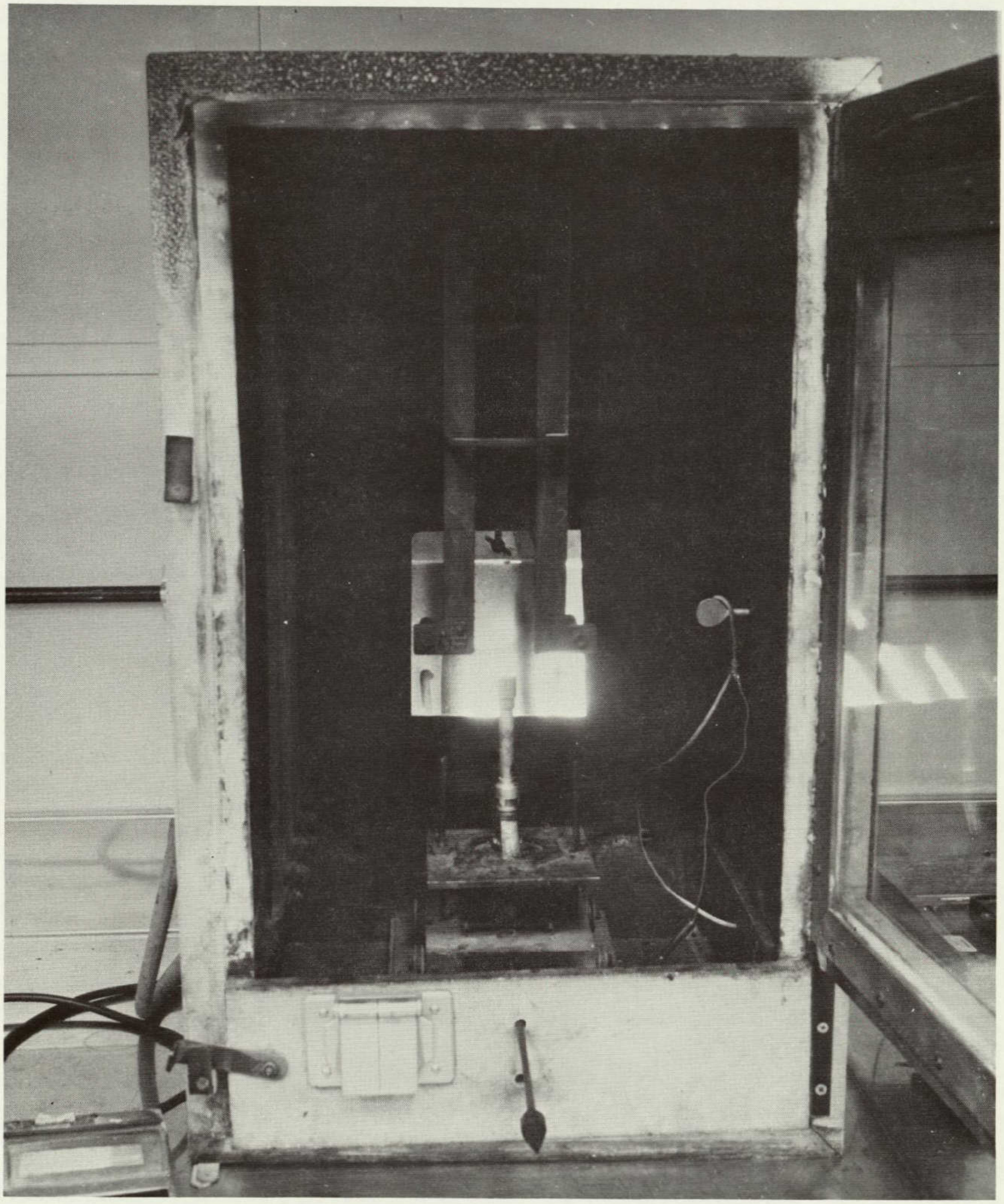


*Figure 3.—Vertical Burn Test Chamber, FAR 25-32 Type*

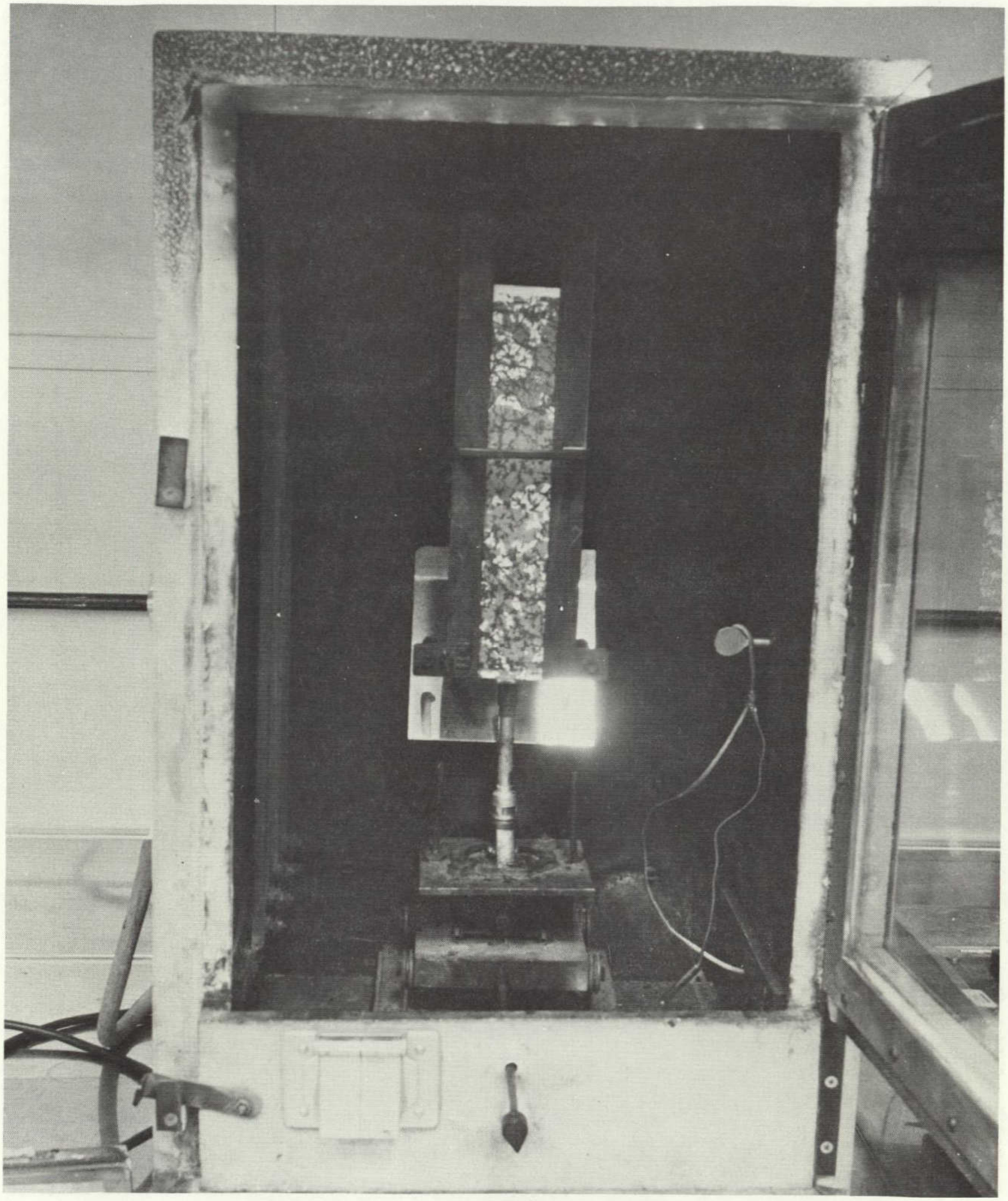


*Figure 4.—Vertical Burn Test Chamber Showing Specimen and Burner Flame Positioning*

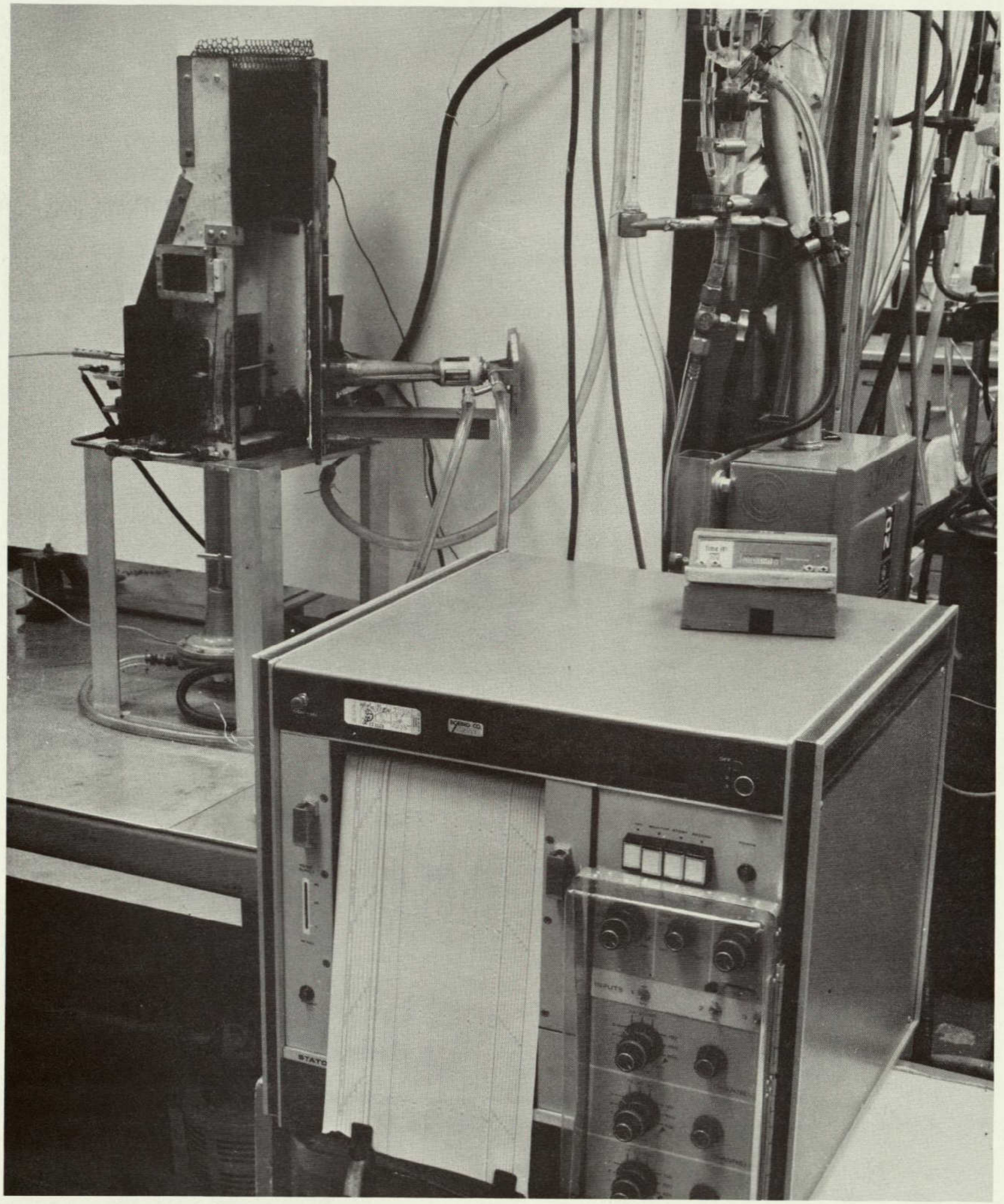


*Figure 5.—Burn-Through Test Apparatus*

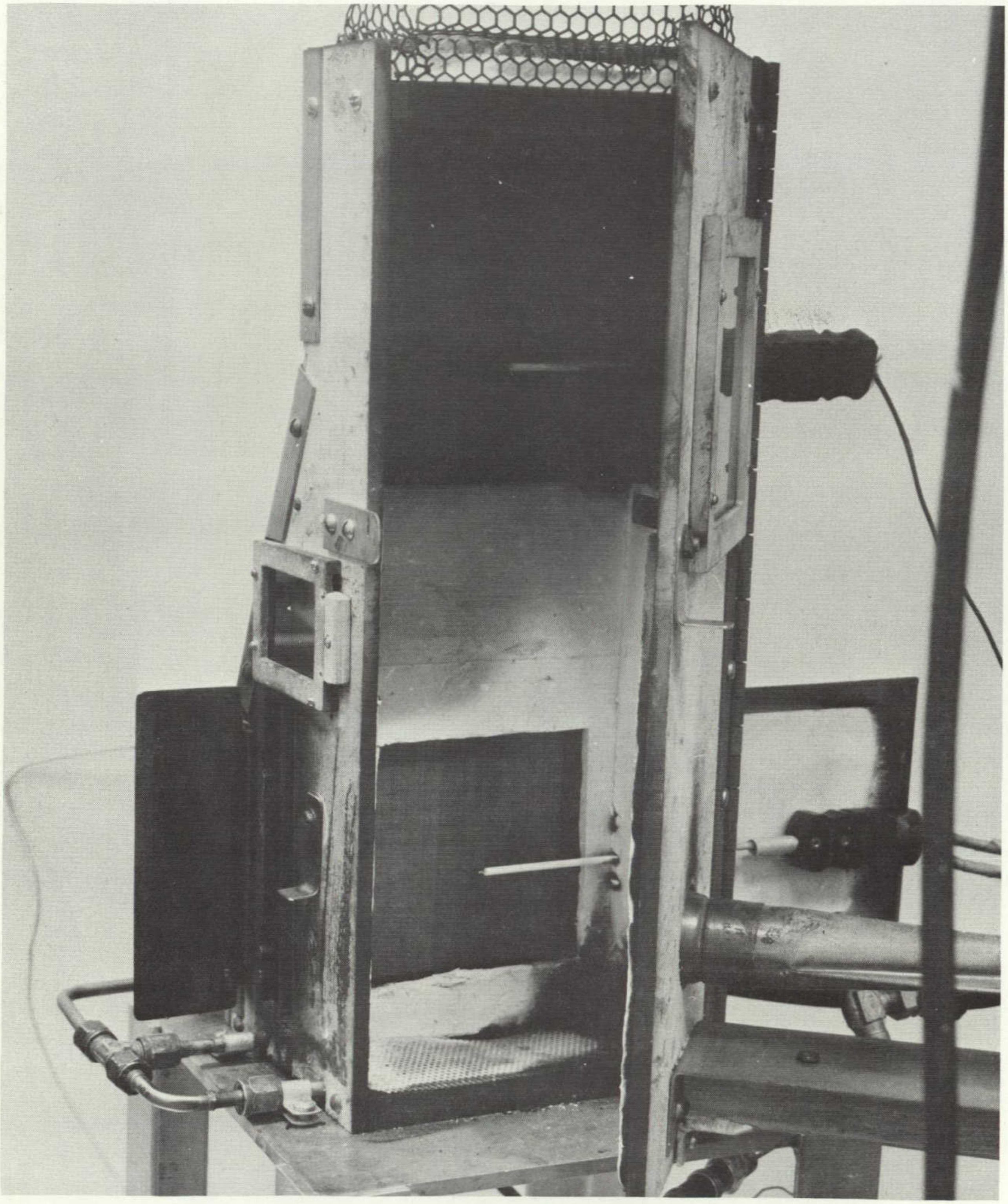


*Figure 6.—Burn-Through Test Chamber Showing Specimen Test Window*

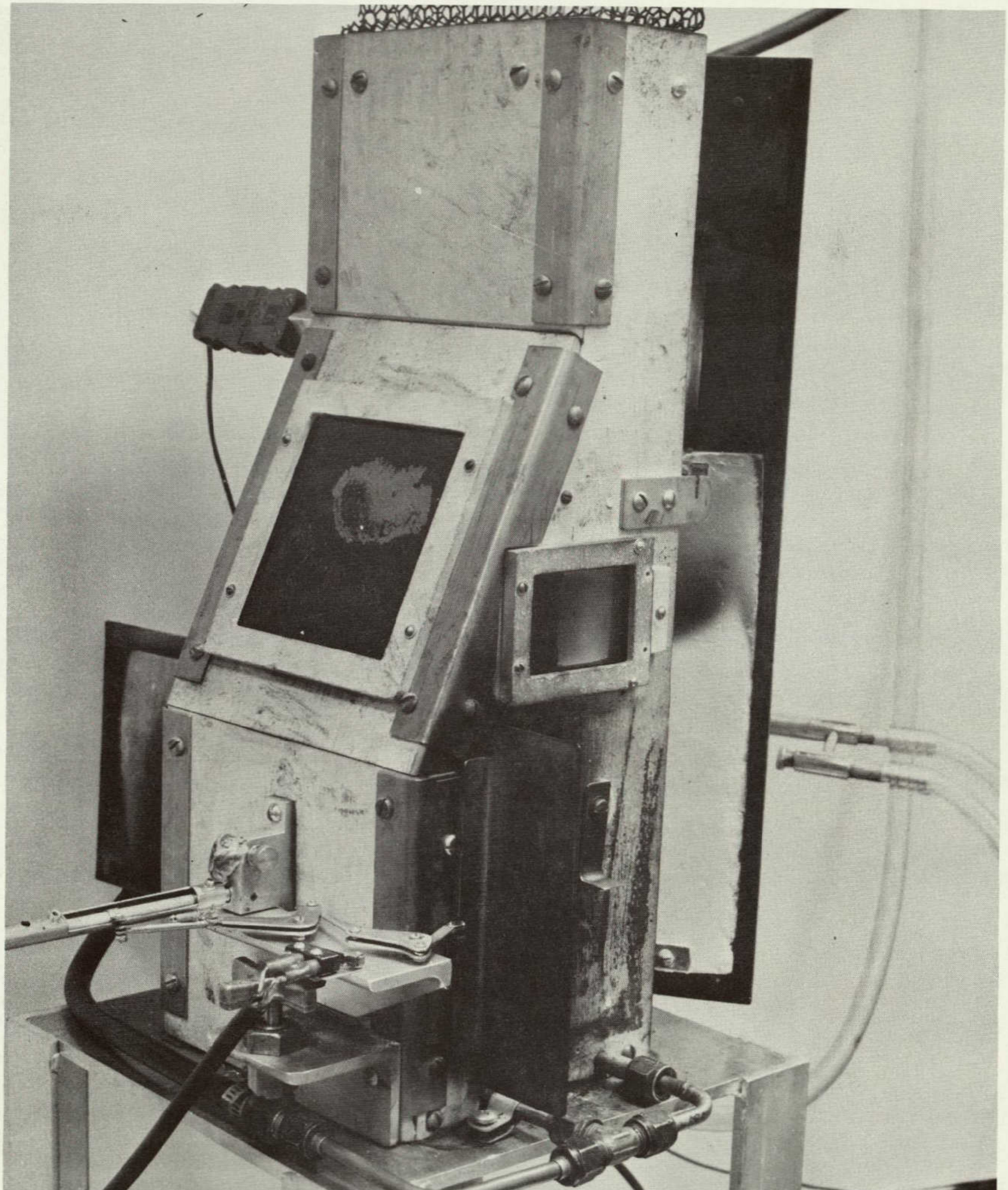


*Figure 7.—Burn-Through Test Apparatus Showing Operation of Backface Thermocouple Levers*

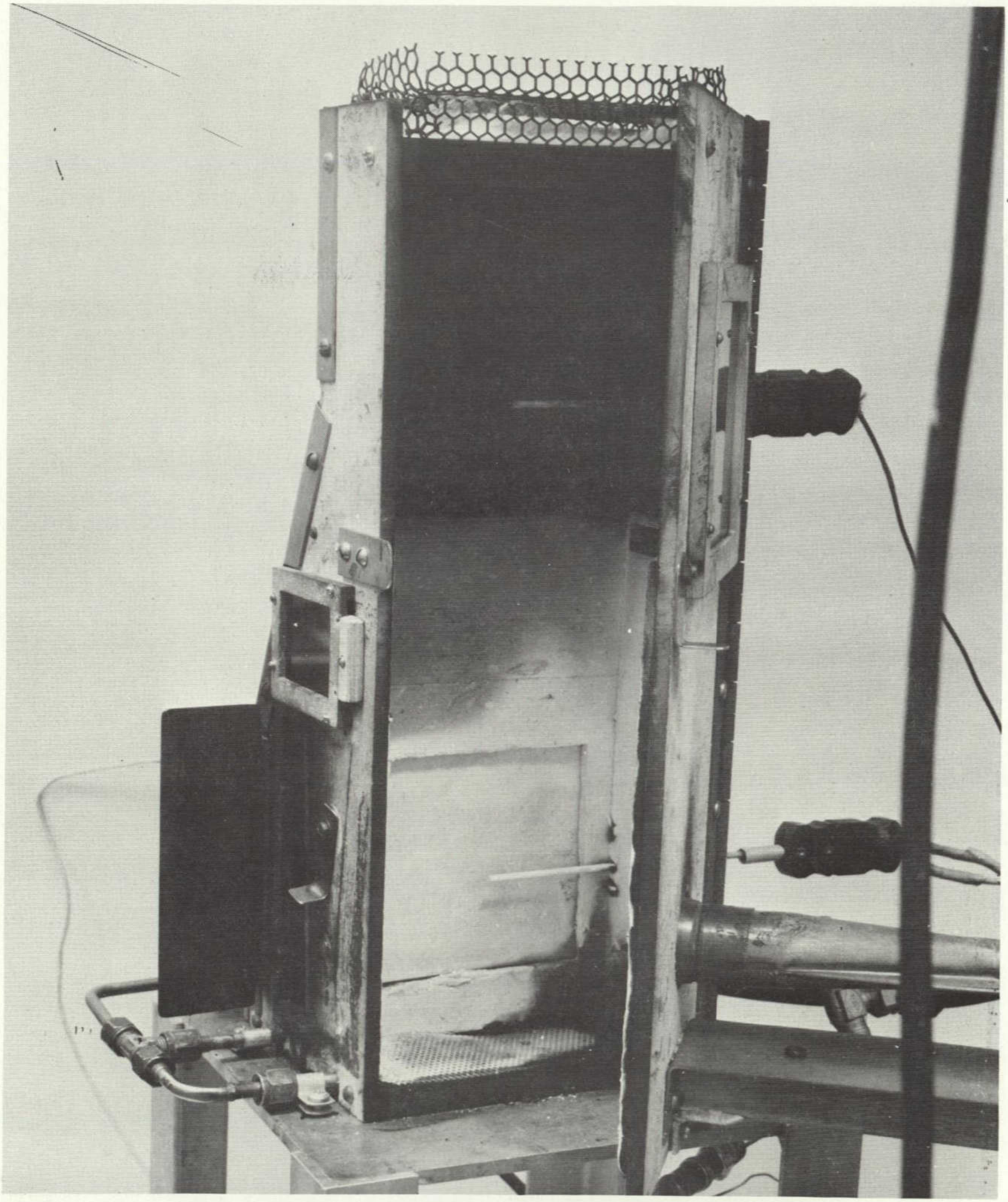


*Figure 8.—Burn-Through Test Apparatus Showing Baffle Positioned in Test Window Preparatory to Starting the Burner*

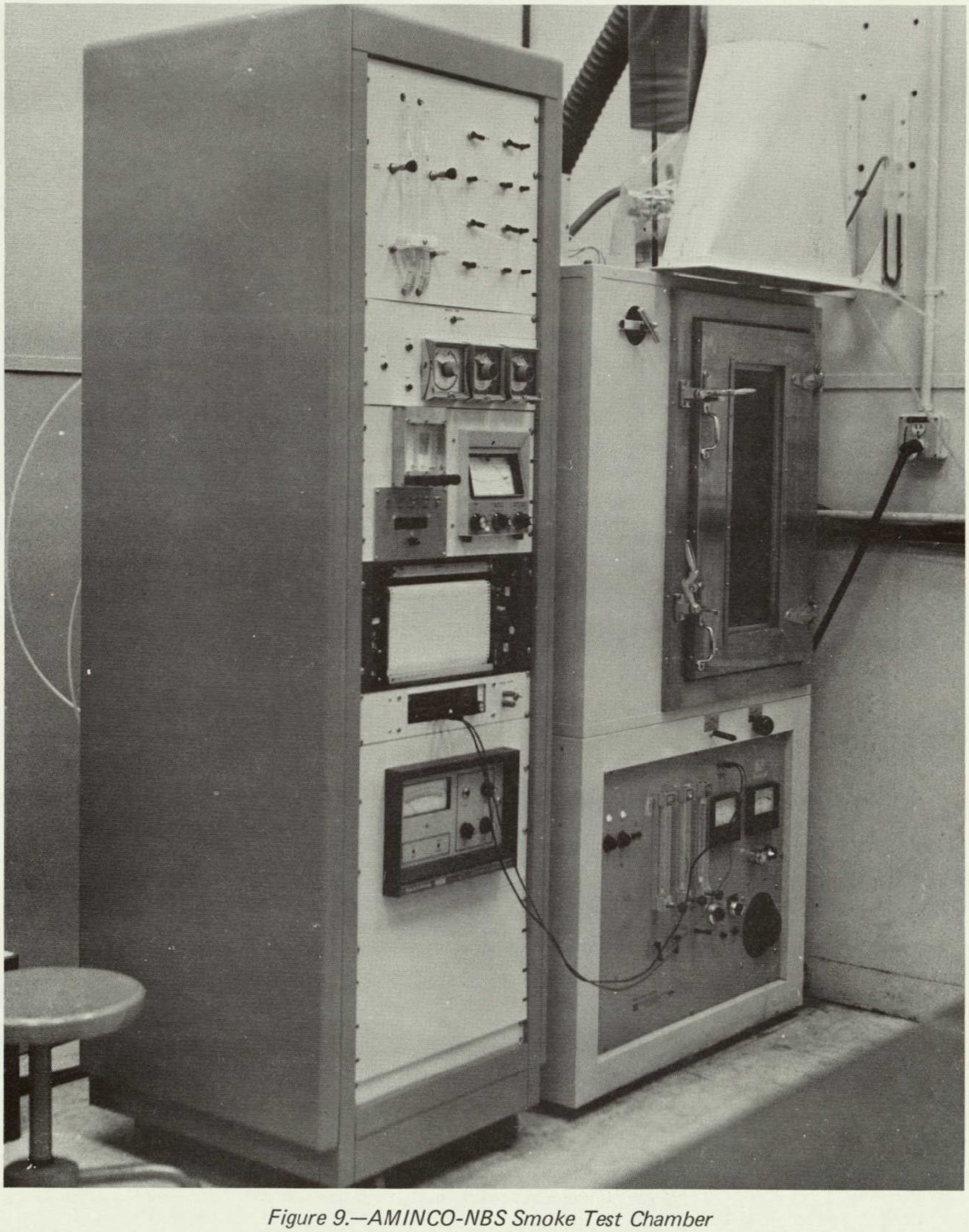


*Figure 9.—AMINCO-NBS Smoke Test Chamber*

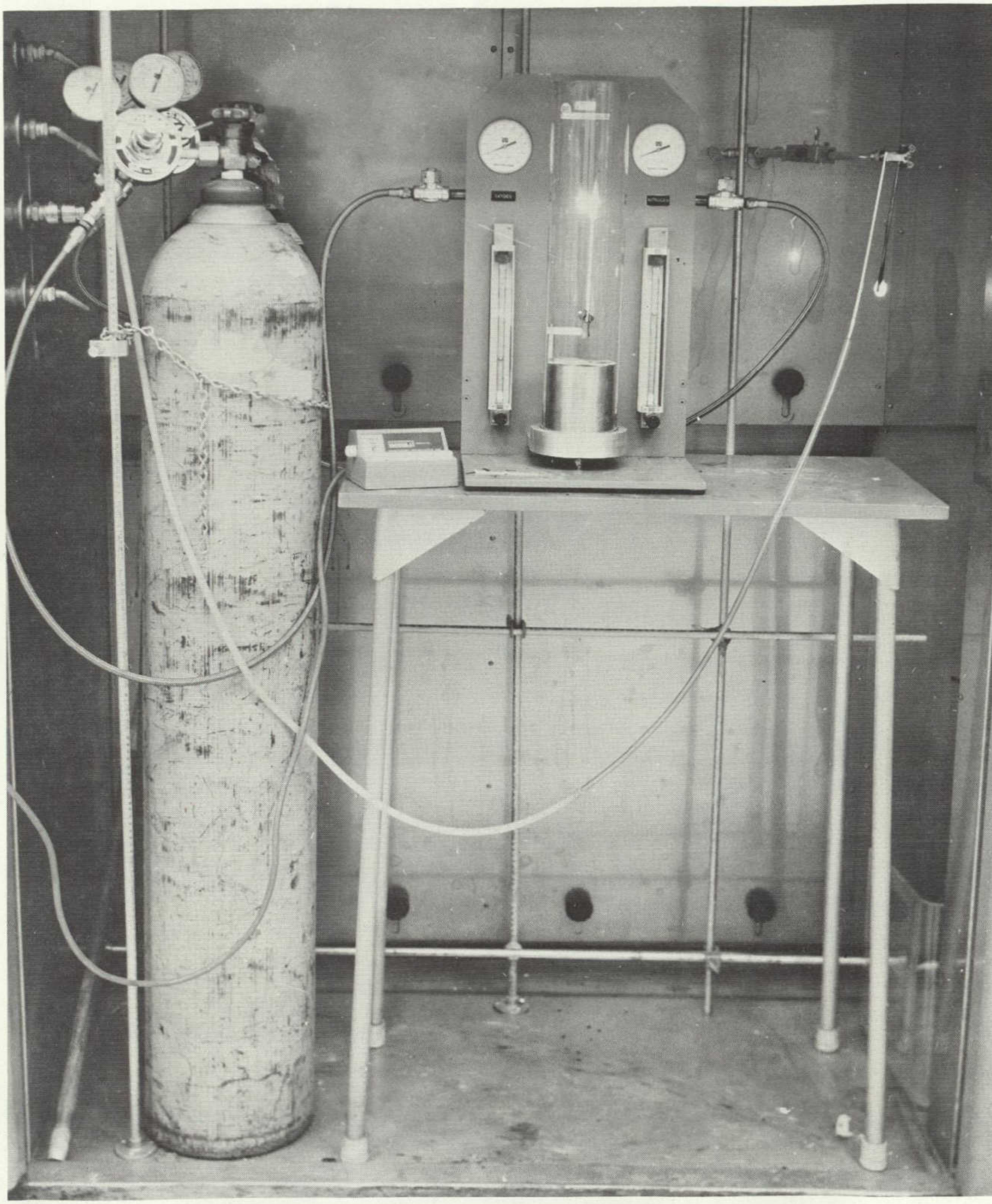


*Figure 10.—ONI Limiting Oxygen Index Tester*

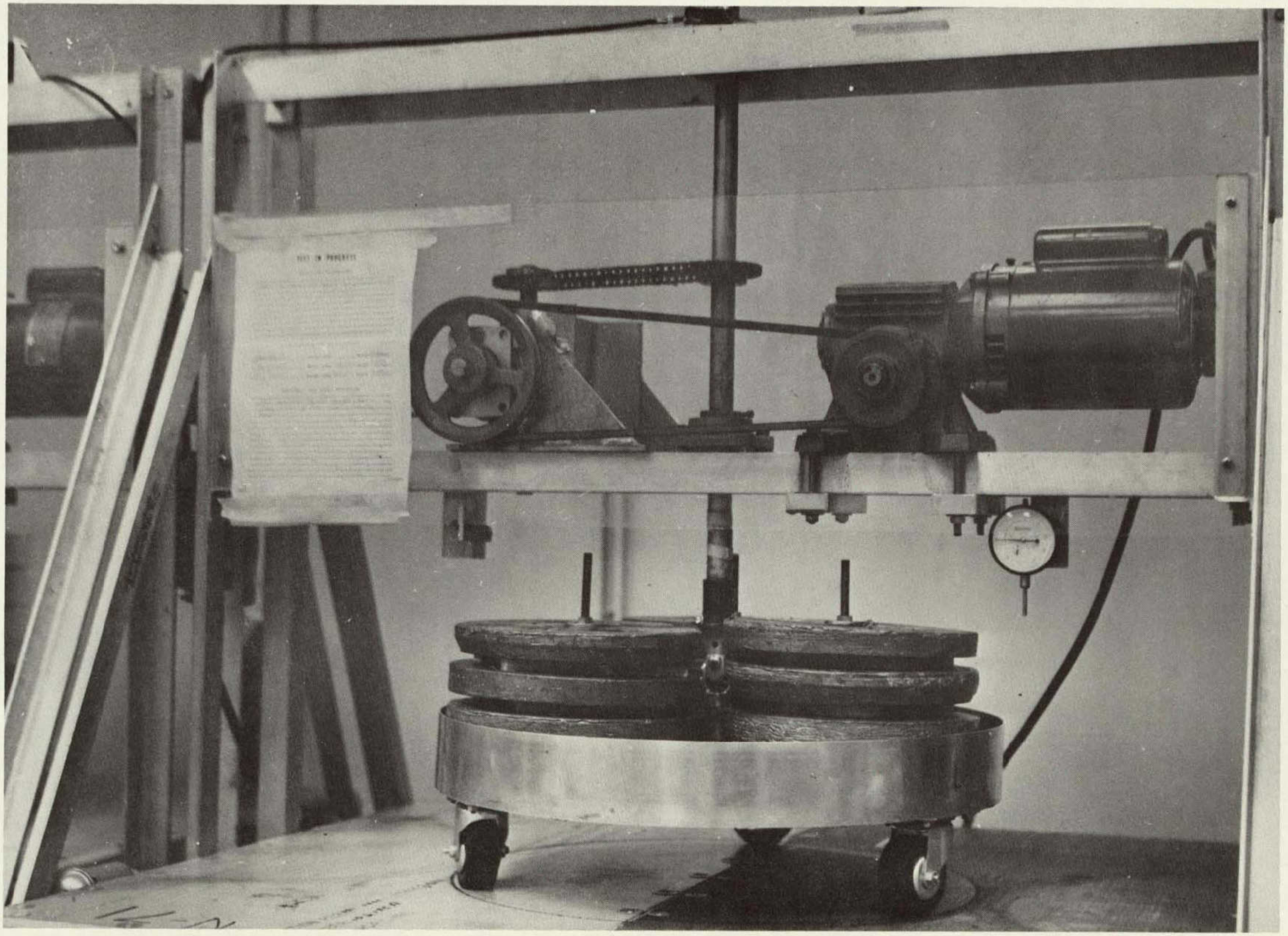


*Figure 11.—Fatigue Tester (Food Cart Roller Test)*

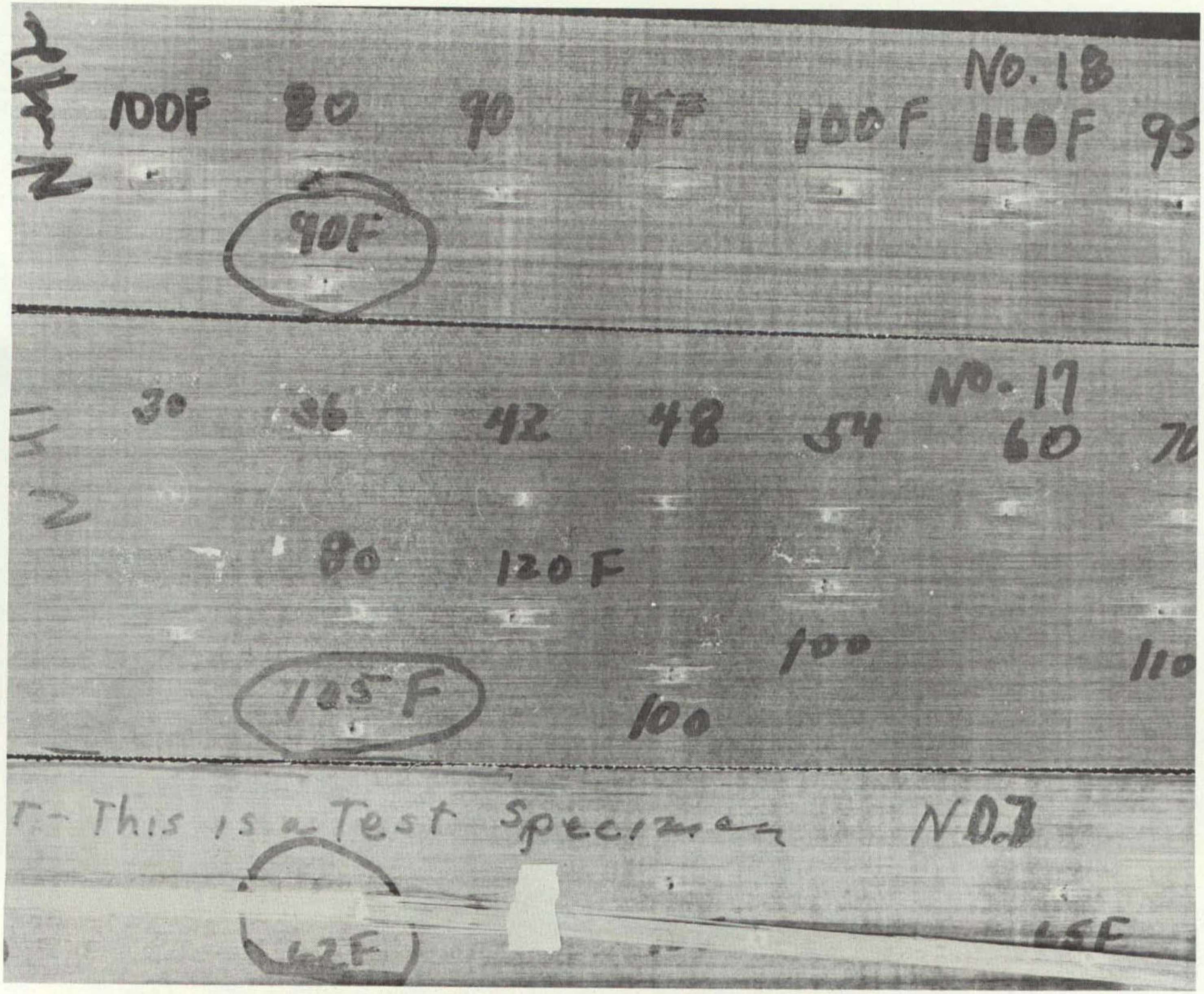



*Figure 12.—Typical Impact Damage to Unidirectionally Reinforced Face Sheets*

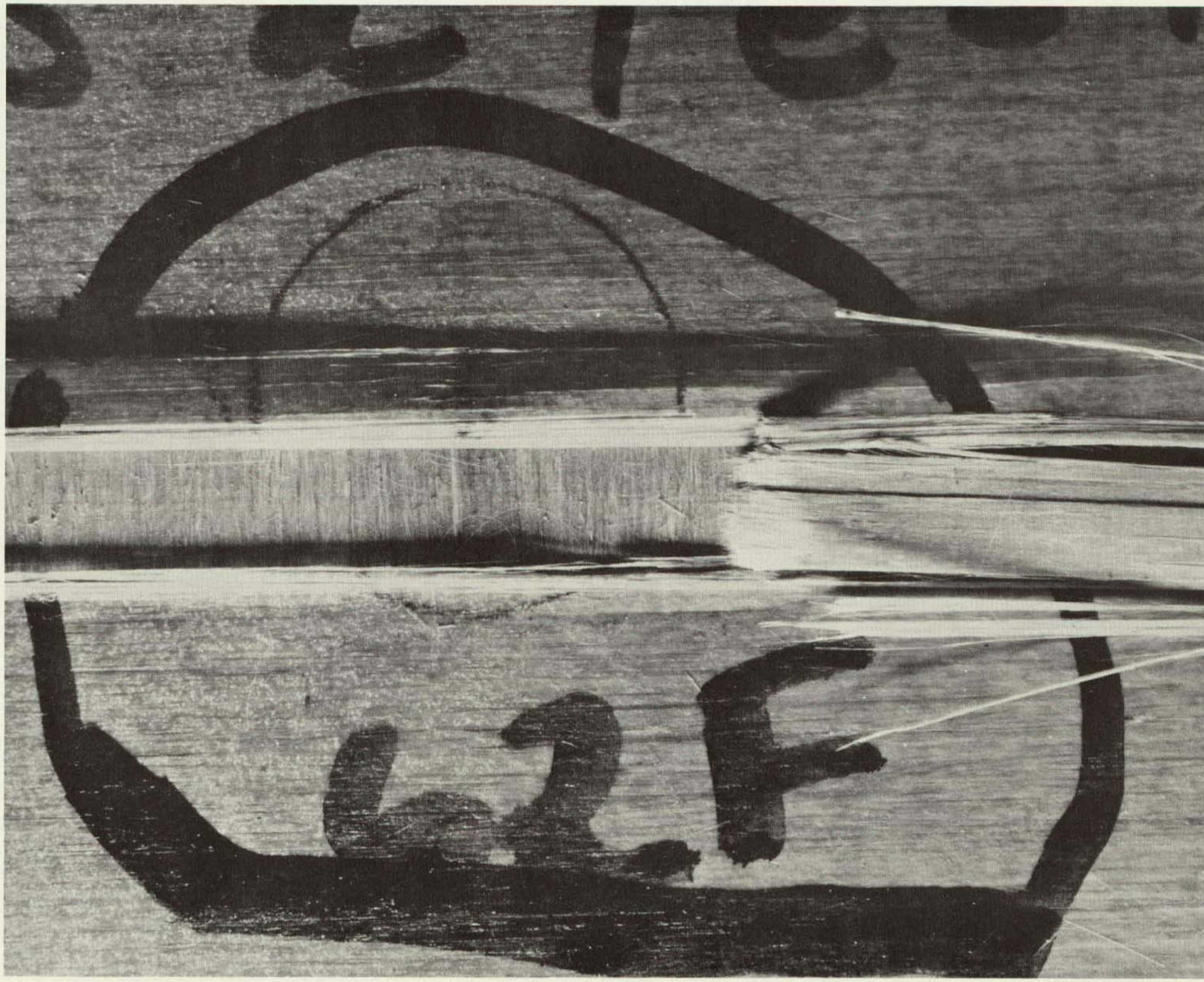


*Figure 13.—Impact Damage to Unidirectionally Reinforced Face Sheet, Panel 7—Magnified 10X*

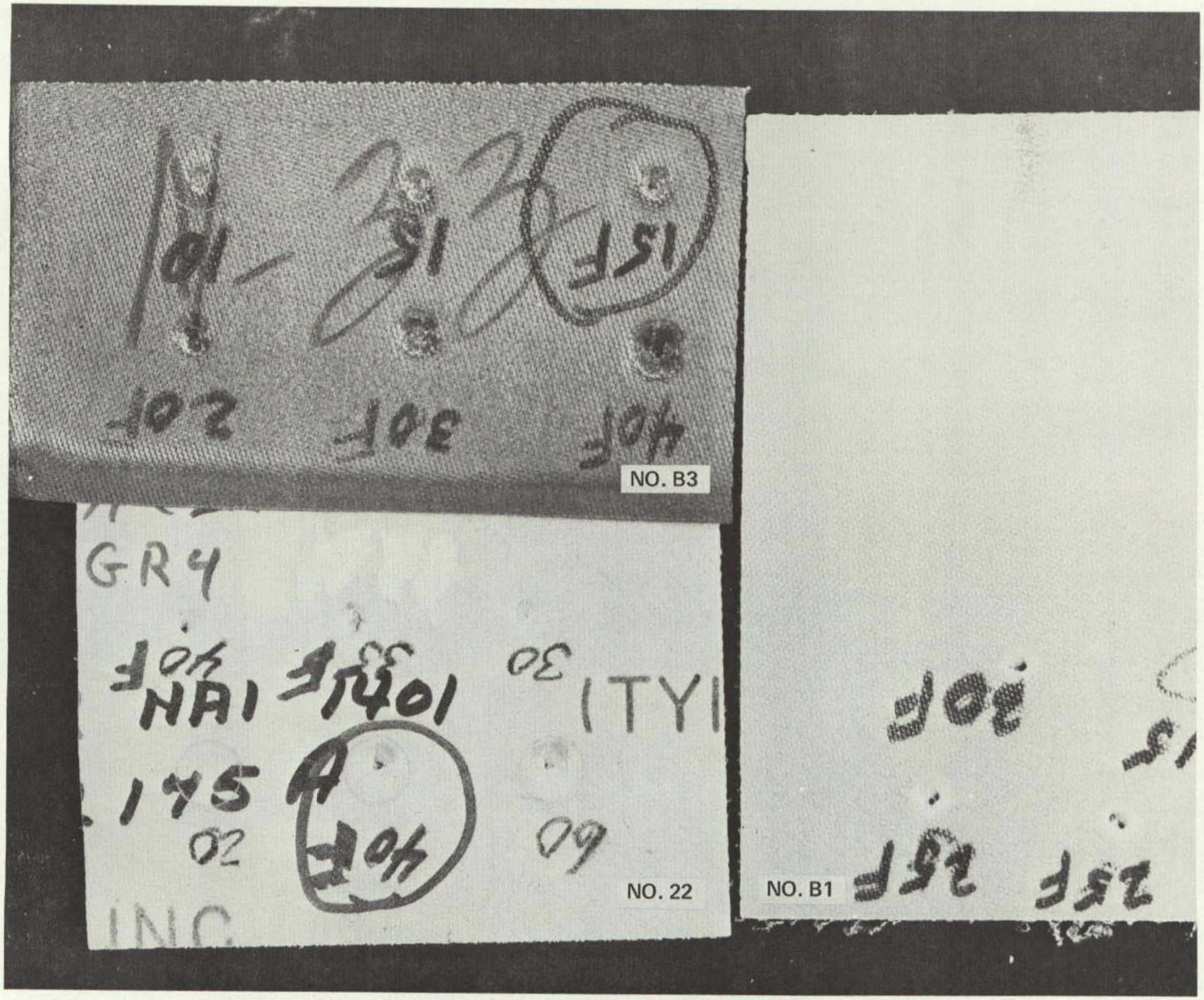



*Figure 14.—Impact Damage to Woven Fabric Reinforced Face Sheet*

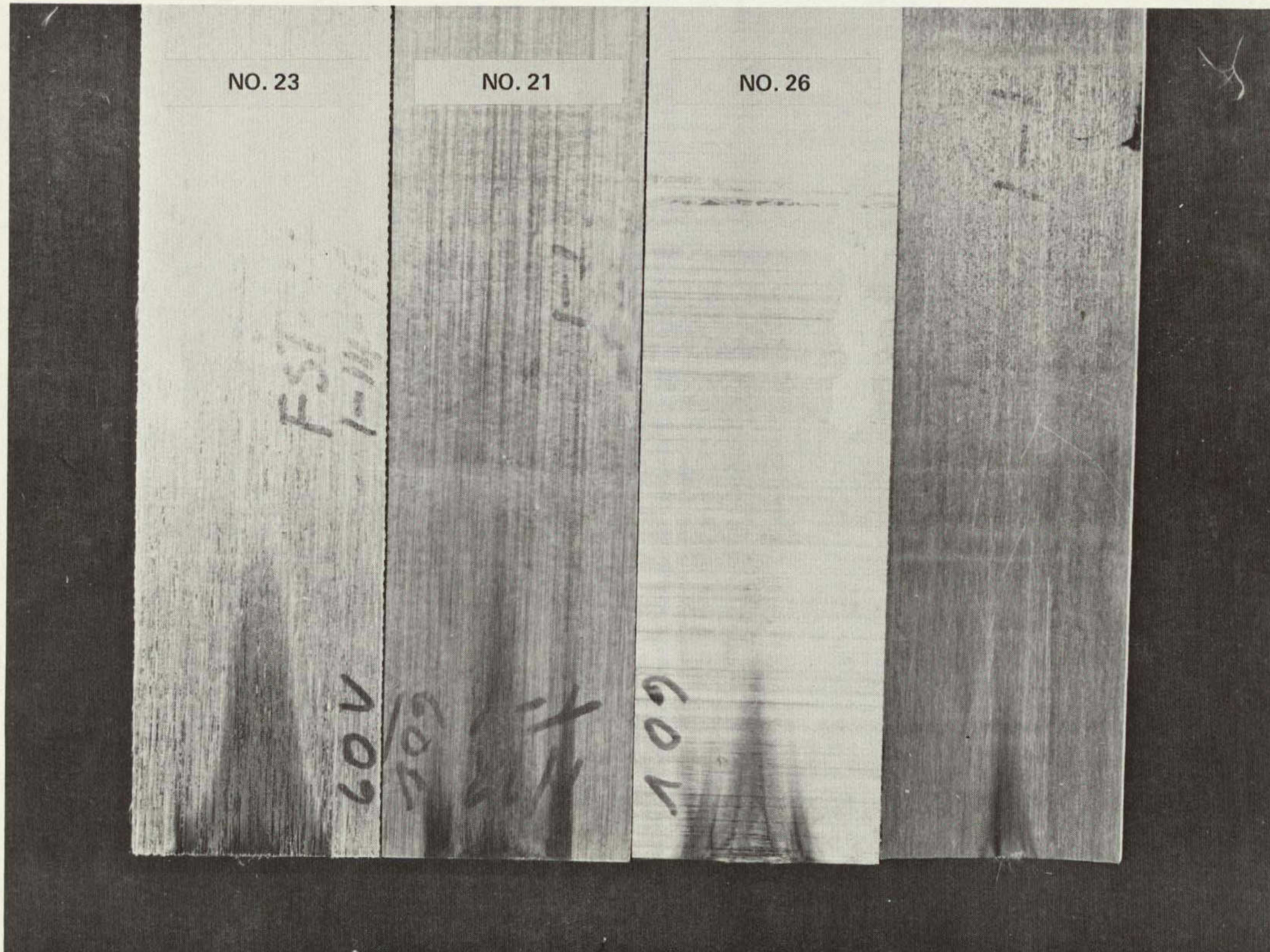



*Figure 15.—FAR 25-32, 60-sec Burn Test Showing Visible Skin Damage to Test Specimens*

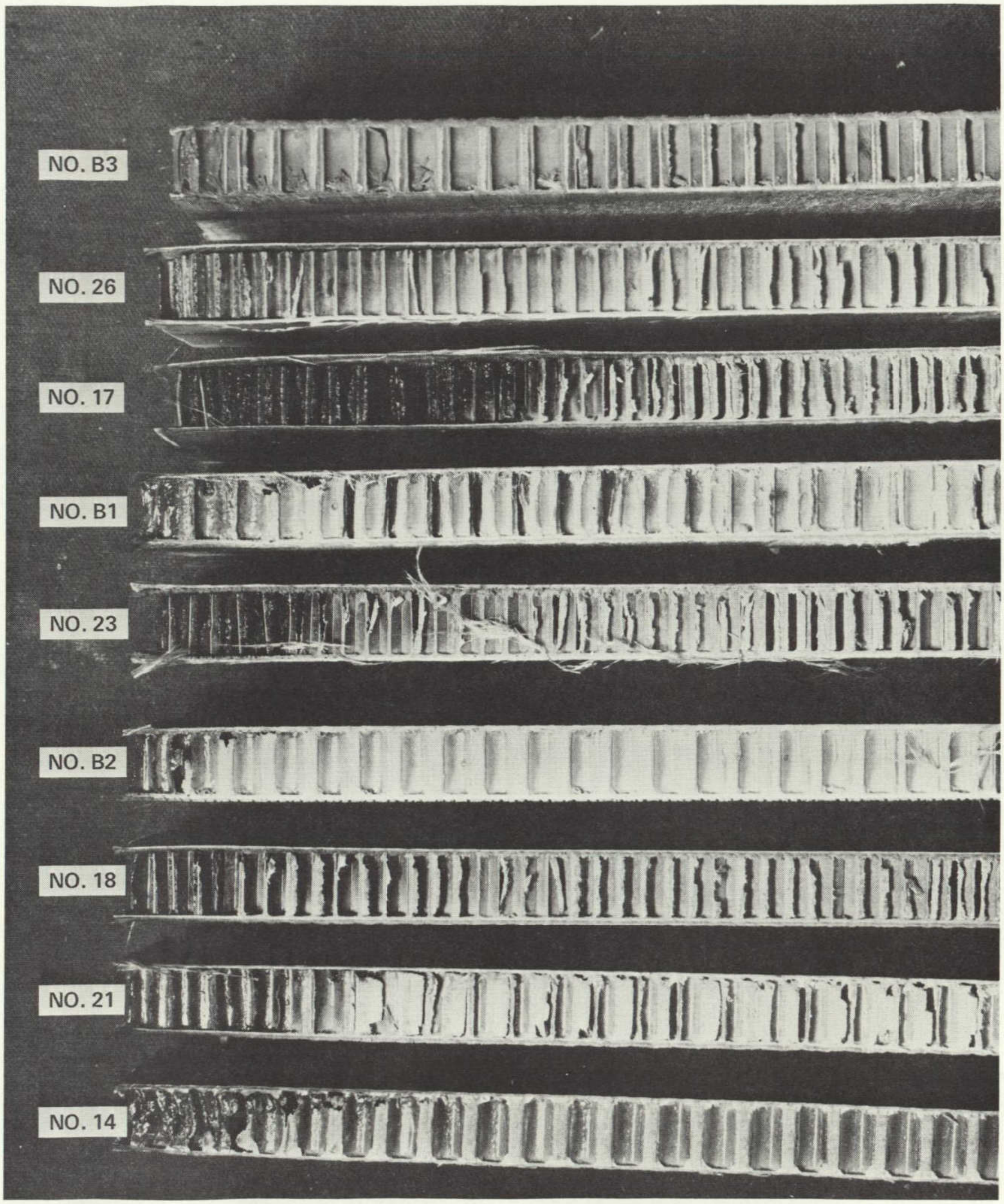



*Figure 16.—FAR 25-32, 60 sec Vertical Burn Test Section View Showing Internal Damage to Test Specimens*

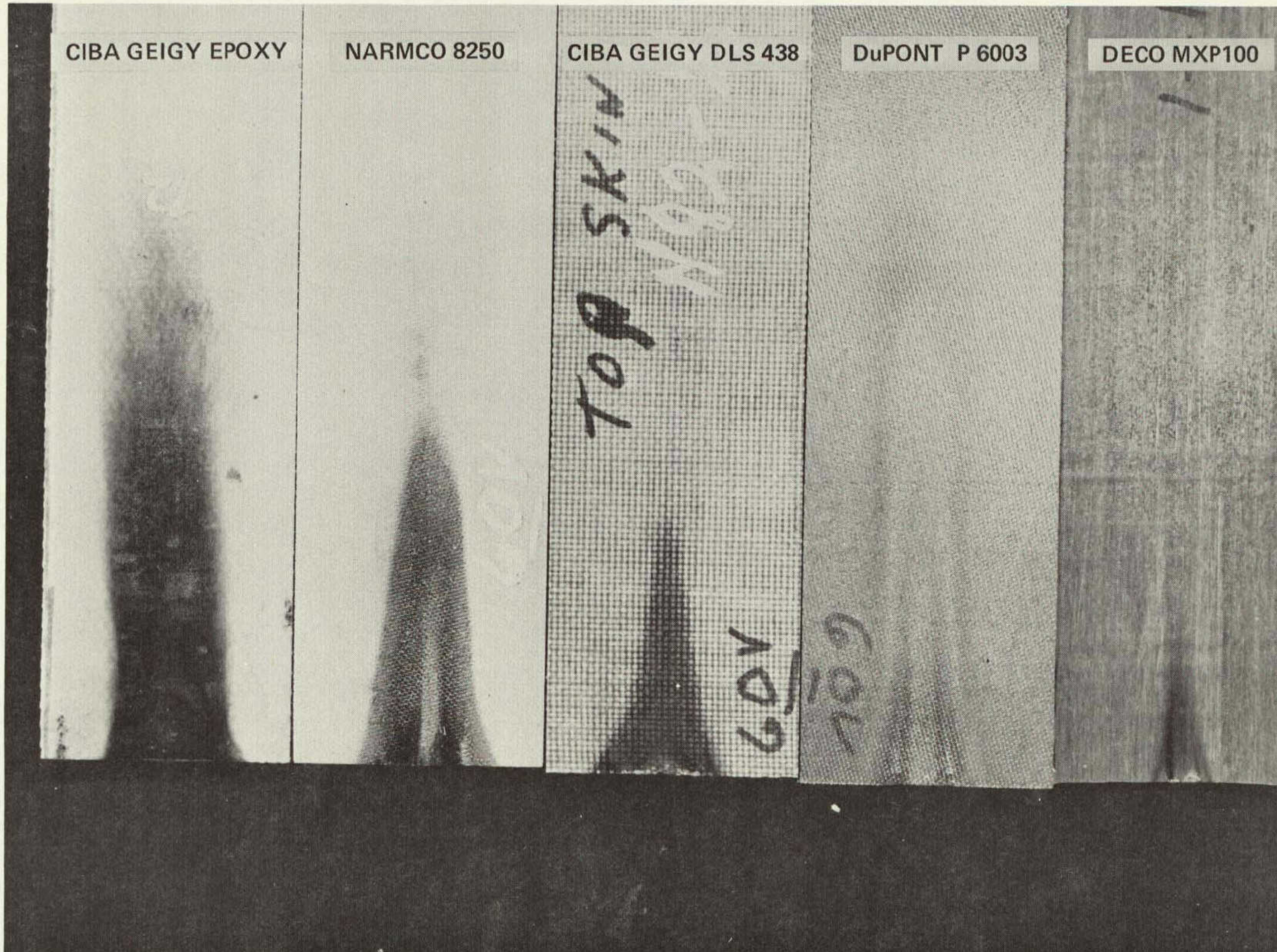



*Figure 17.—FAR 25-32, 60-sec Vertical Burn Test Comparison of All the Face Sheet Resin Systems Tested*

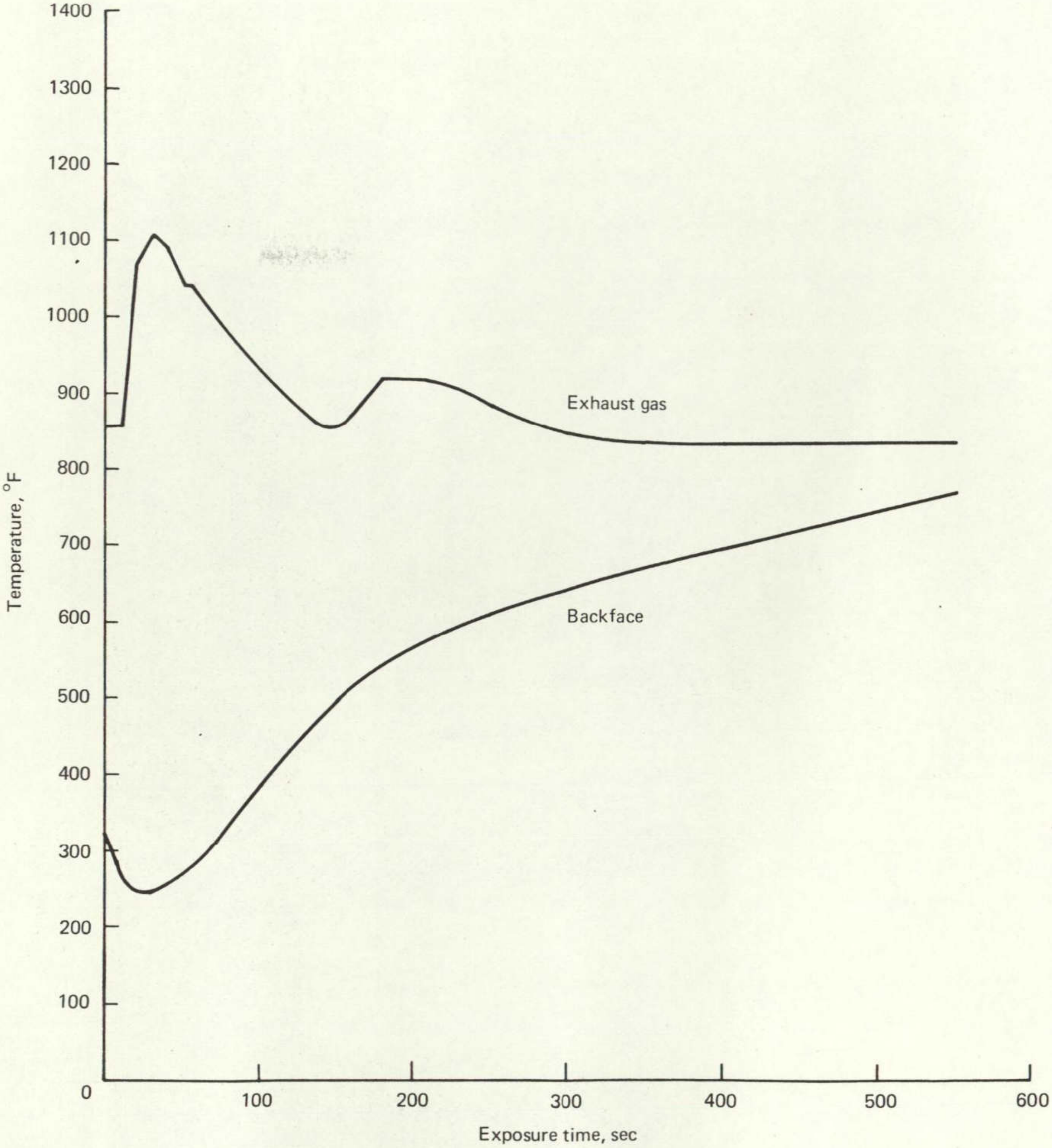



*Figure 18.—Burn-Through Test, Panel 15, Run No. 1*

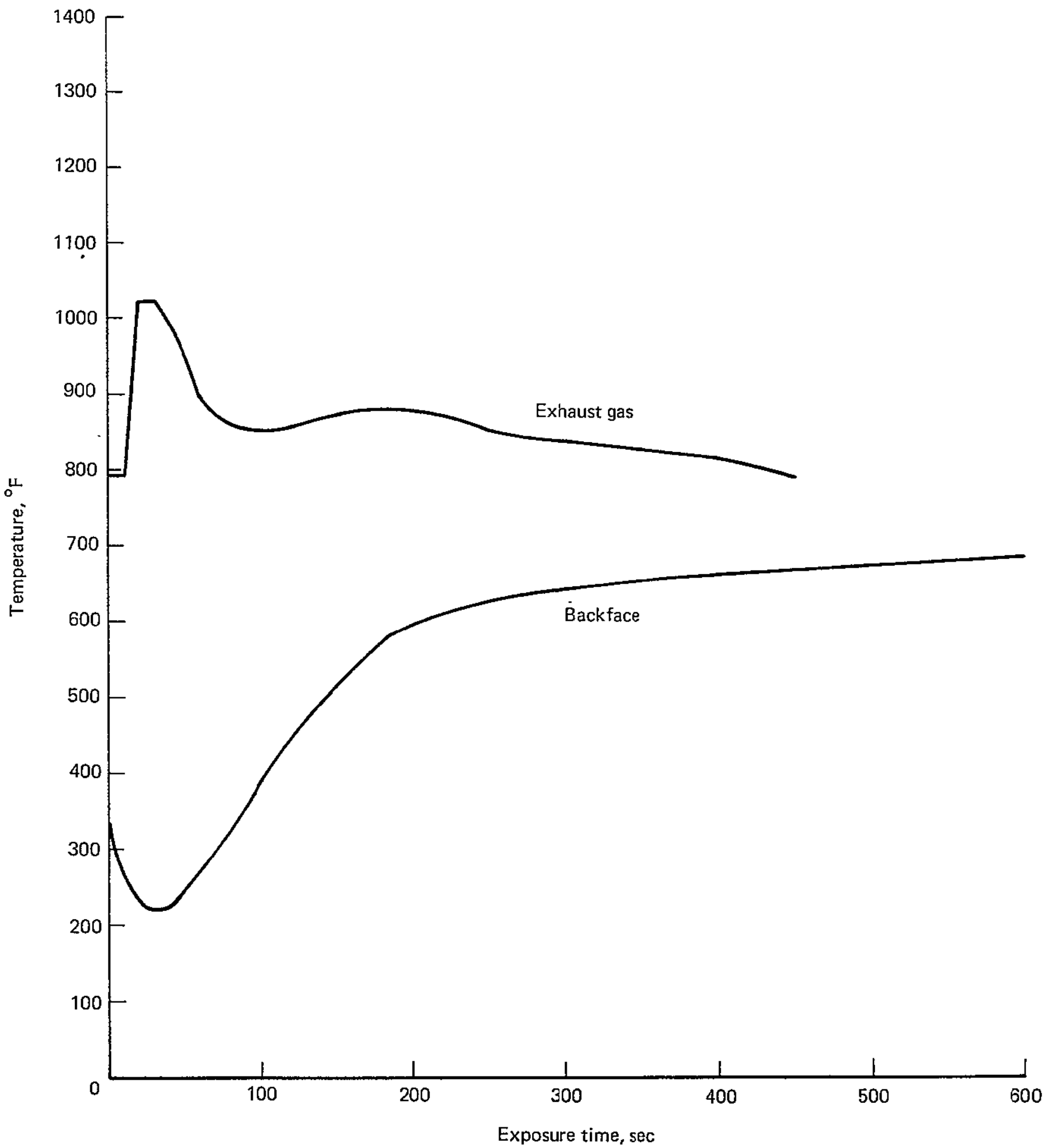



*Figure 19.—Burn-Through Test, Panel 15, Run No. 2*

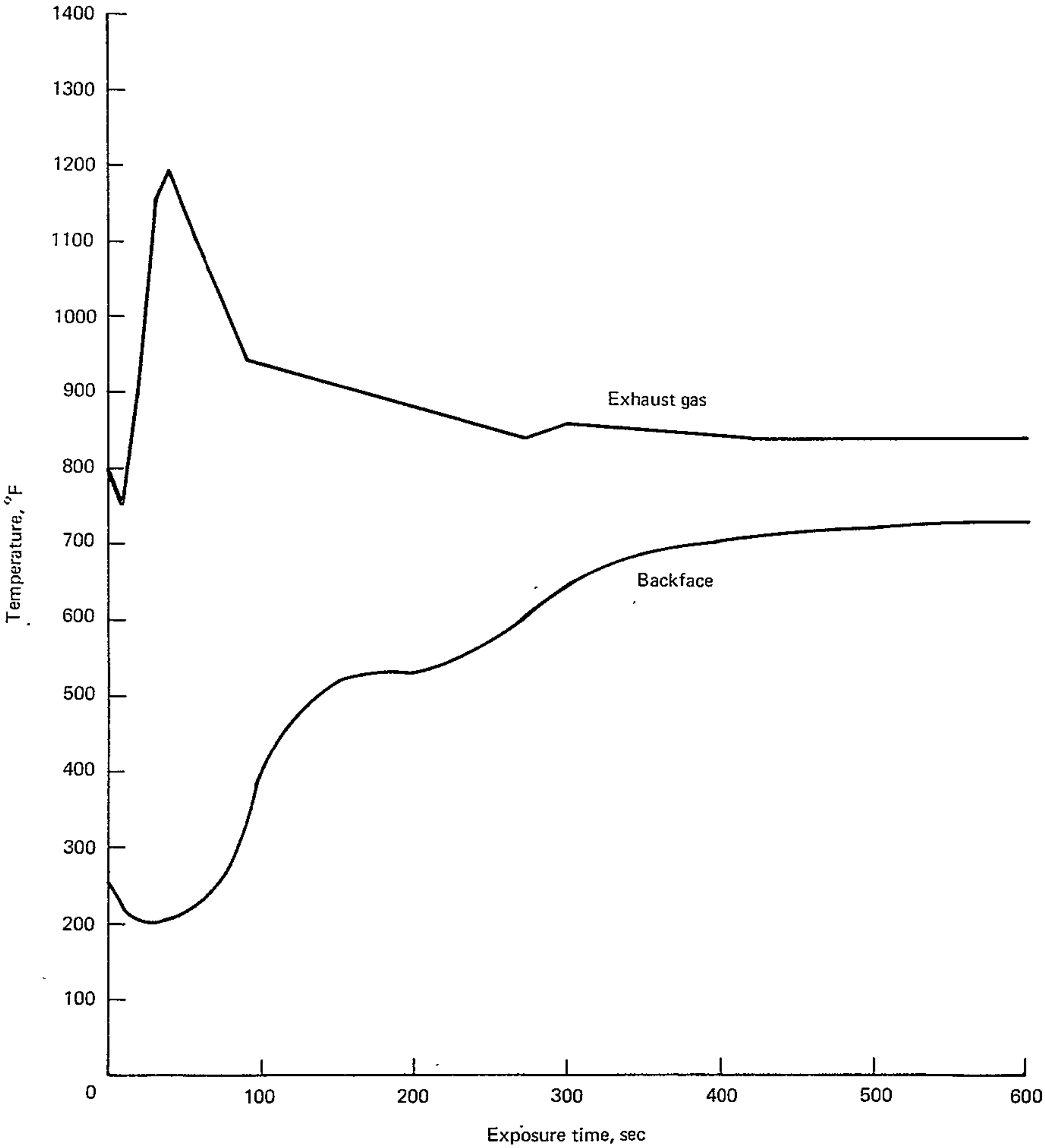



*Figure 20.—Burn-Through Test, Panel 22, Run No. 1*

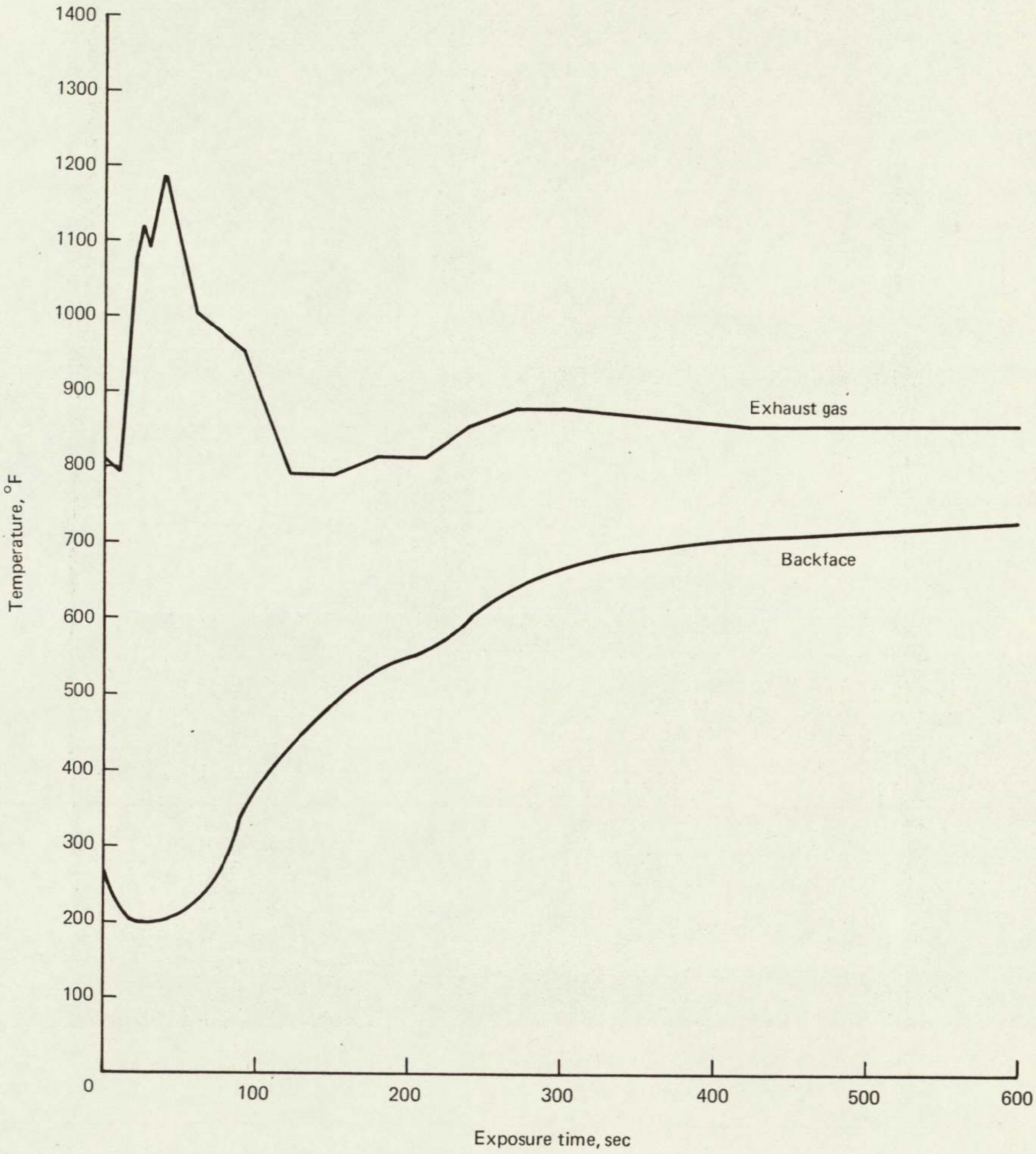



*Figure 21.—Burn-Through Test, Panel 22, Run No. 2*

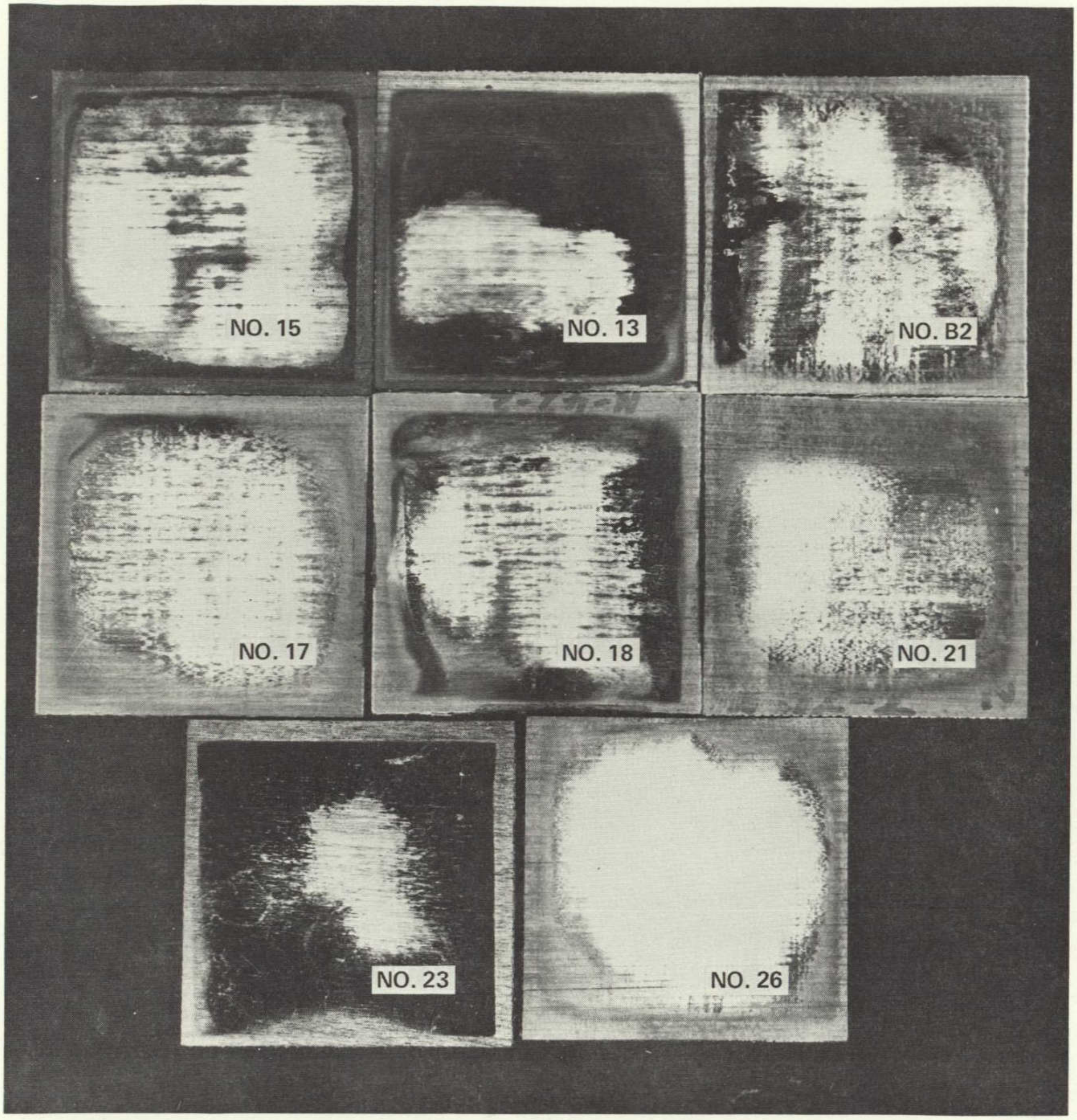



*Figure 22.—Burn-Through Test Data—Typical Damage to Exposed (Heated) Face, Unidirectionally Reinforced Face Sheet Material, 10-min Test*

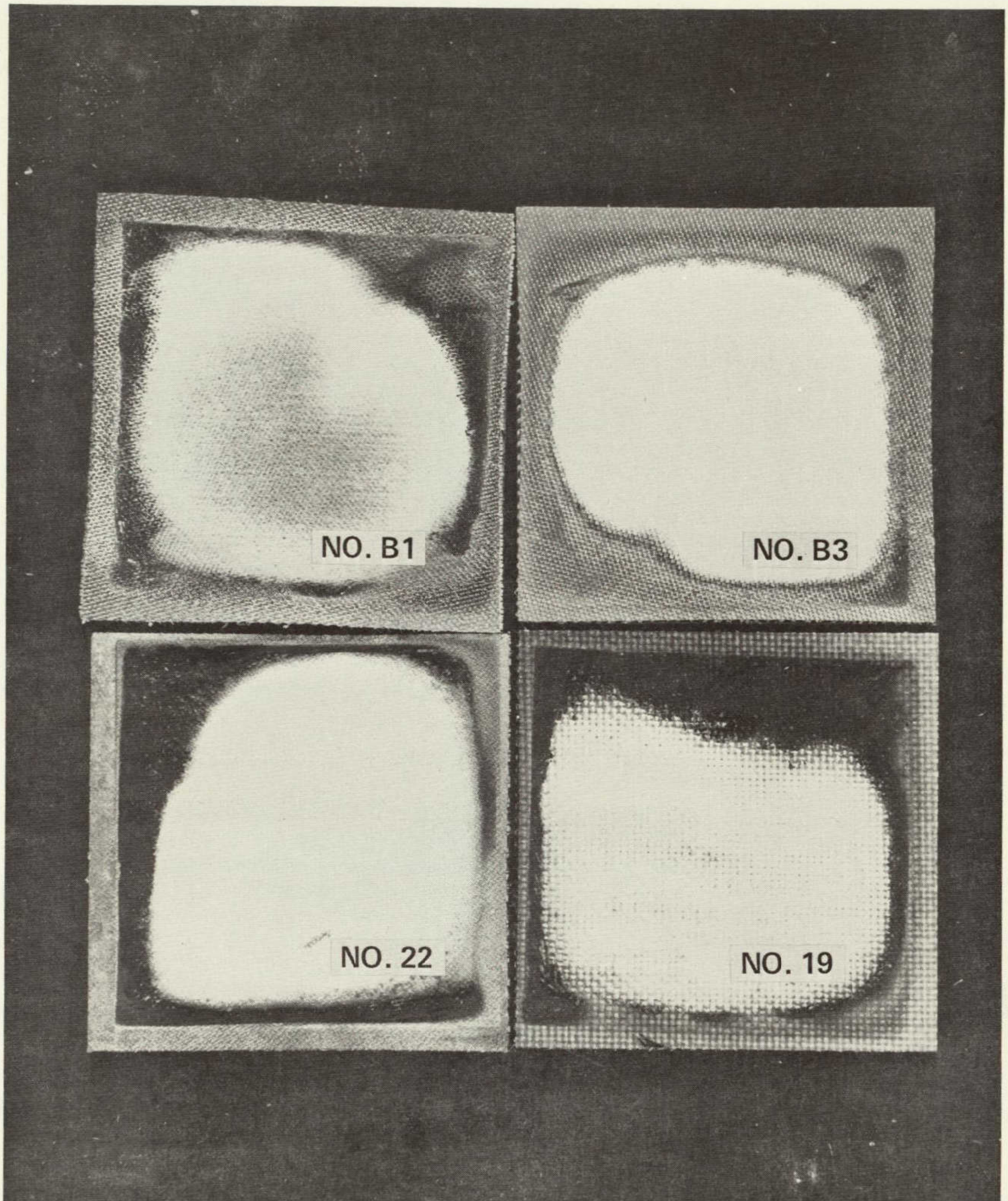



*Figure 23.—Burn Through Test Data—Typical Damage to Exposed (Heated) Face, Woven Fabric Reinforced Face Sheet Material, 10-min Test*

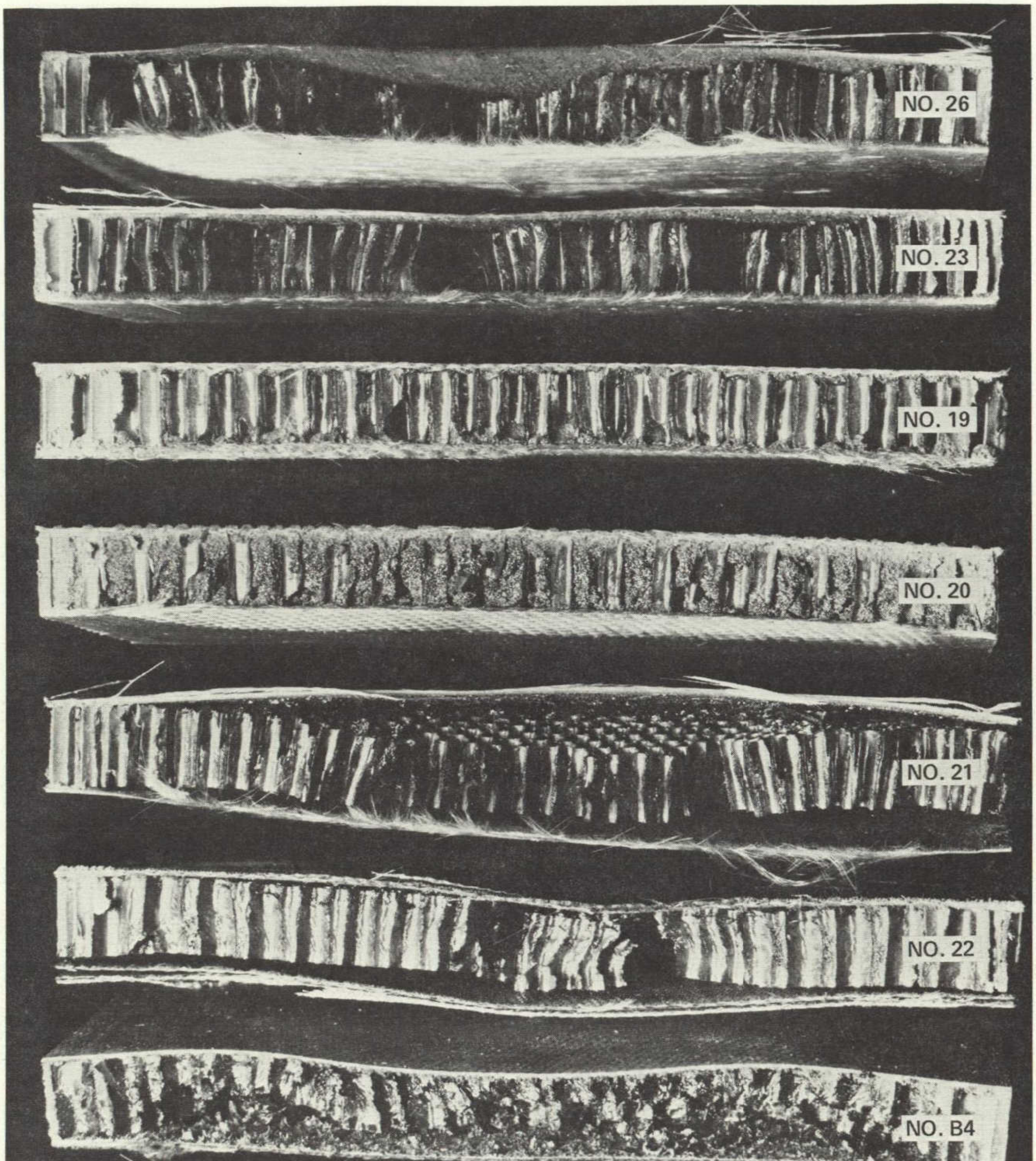



*Figure 24.—Burn-Through Test Showing Typical Internal Damage—Section View of Test Specimens, 10-min Test*

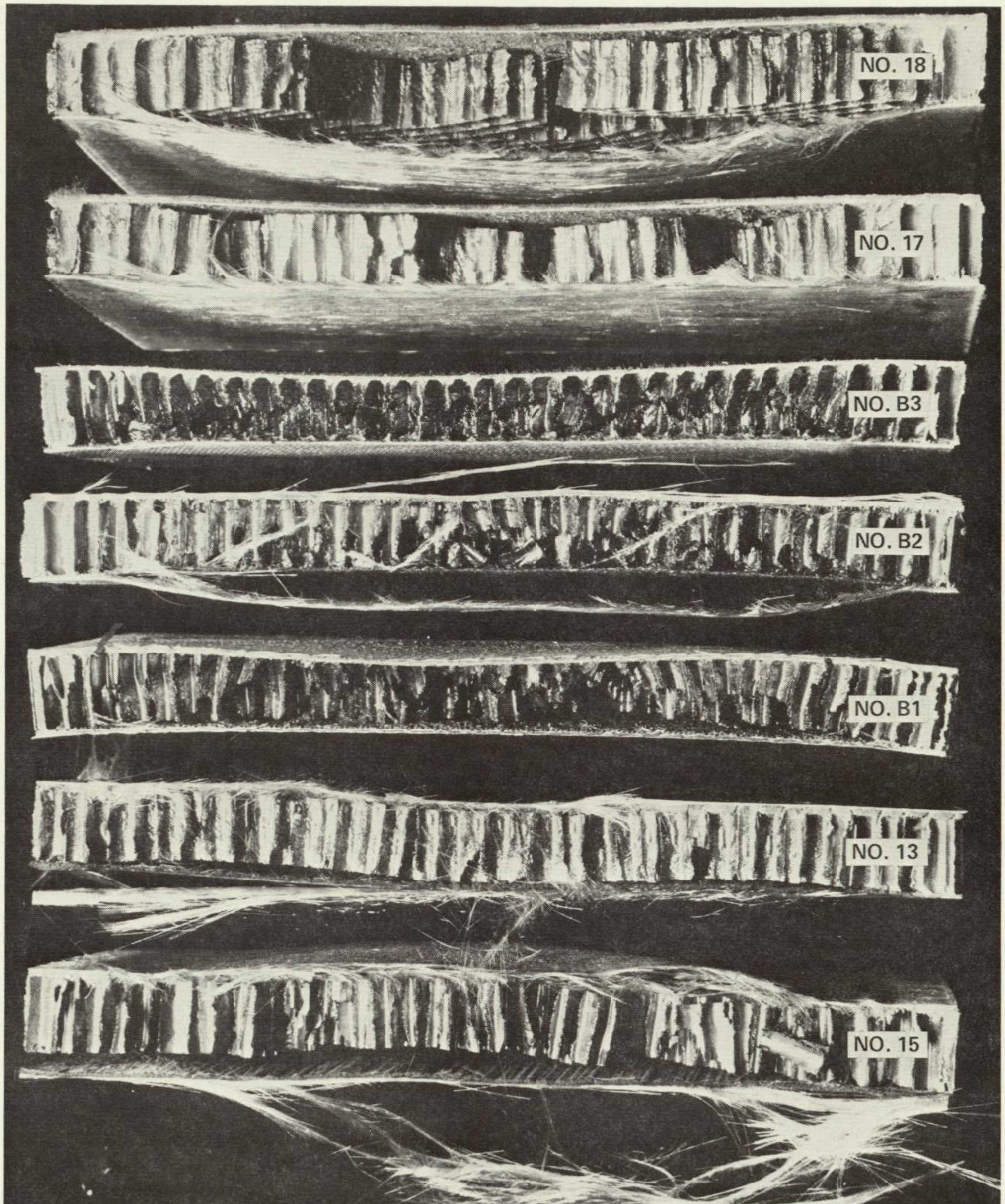



*Figure 25.—Burn-Through Test Showing Typical Internal Damage—Section View of Test Specimens, 10-min Test*

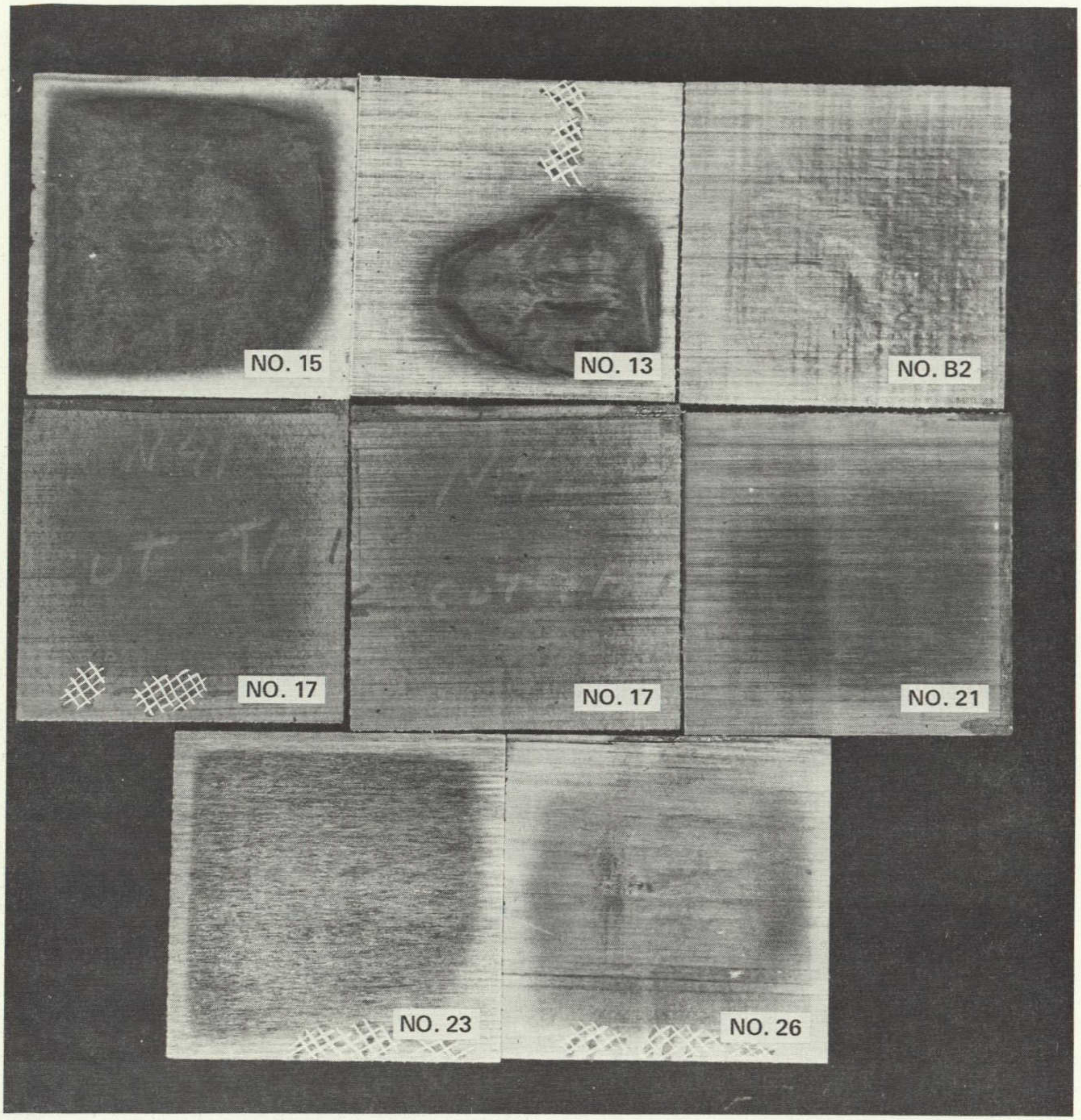



*Figure 26.—Burn-Through Test—Typical Appearance of Back-(Unexposed) Face After 10-min Test*

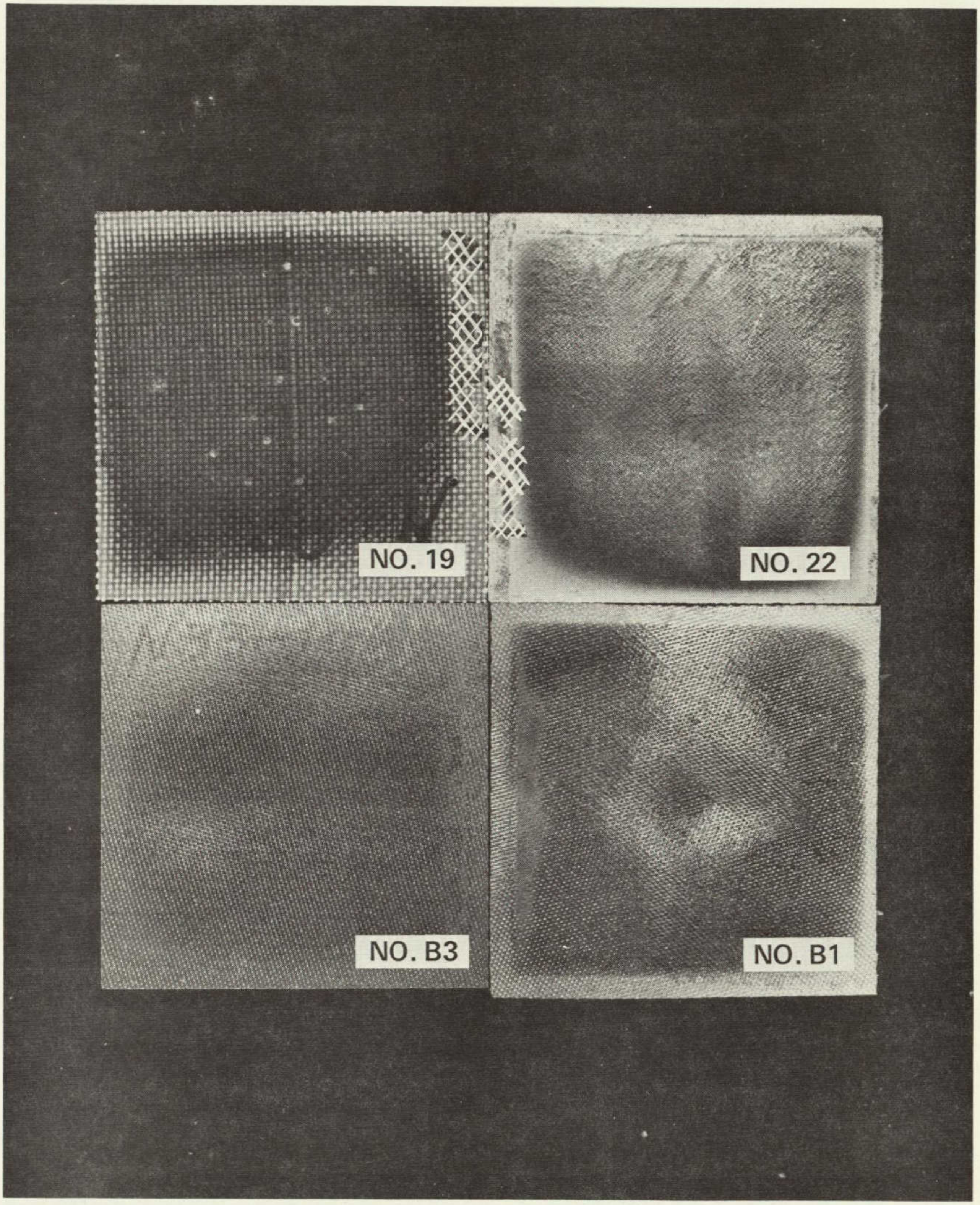



*Figure 27.—Burn-Through Test—Typical Appearance of Back-(Unexposed) Face After 10-min Test*

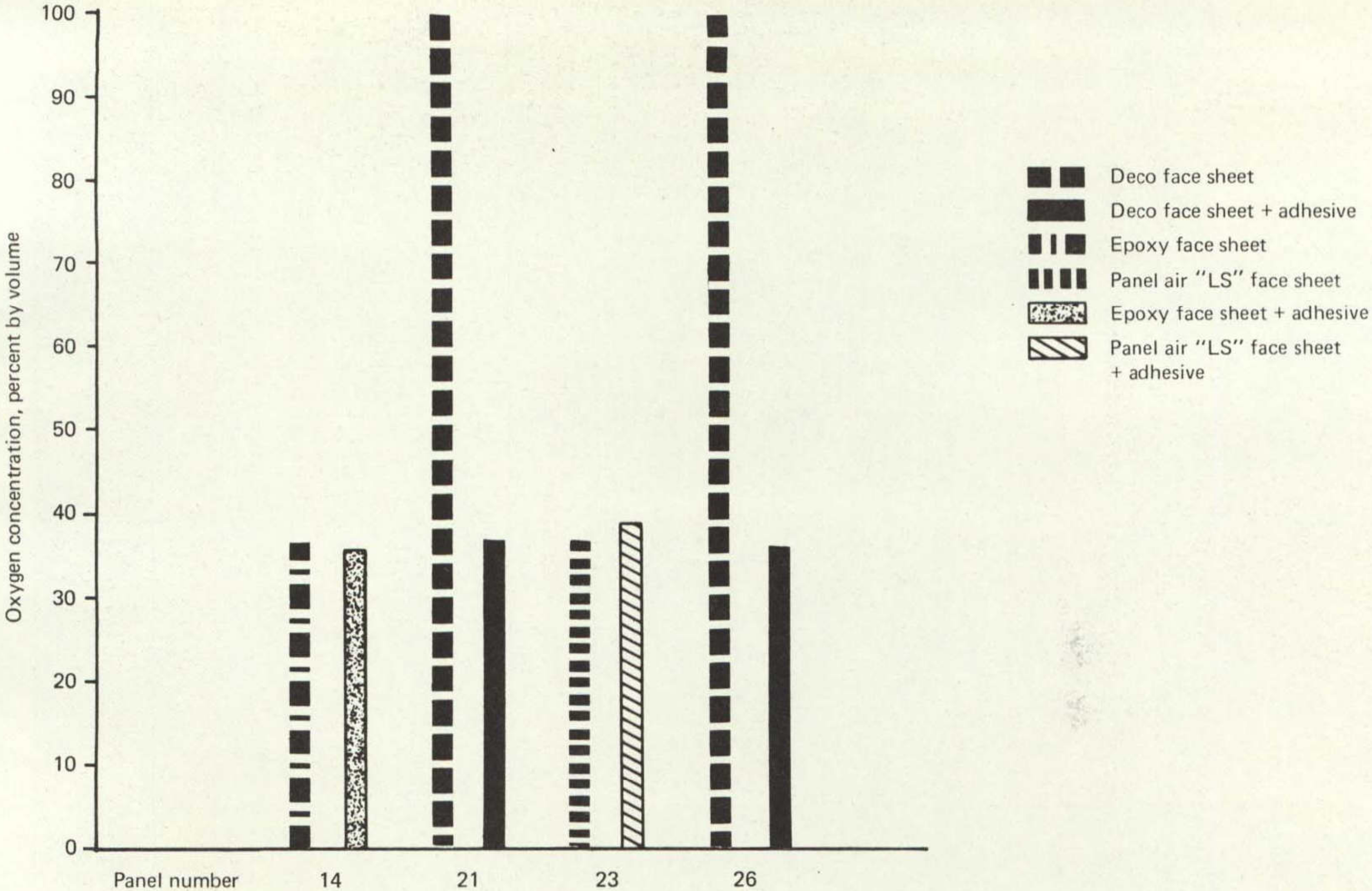



*Figure 28.—Oxygen Index Values*

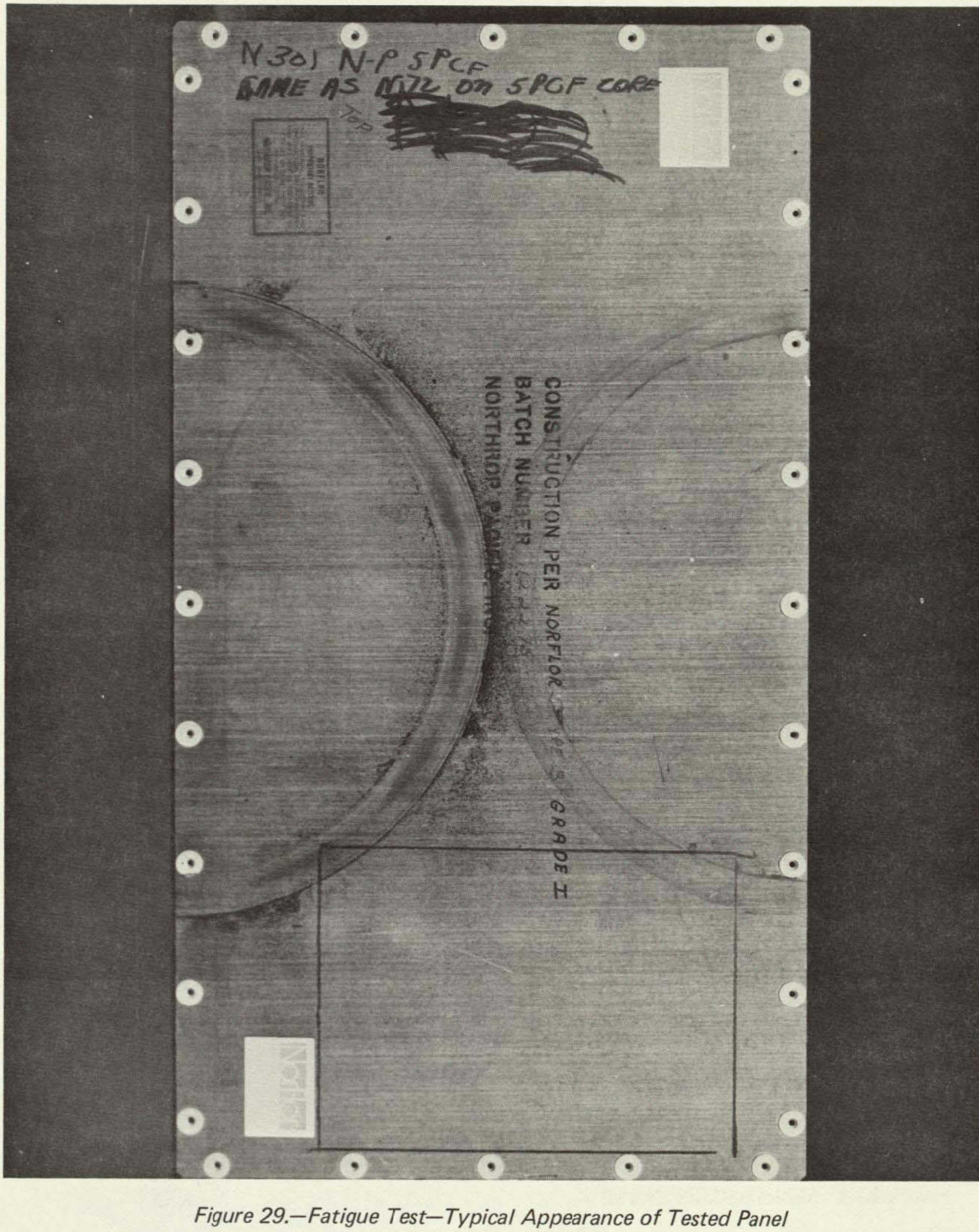



*Figure 29.—Fatigue Test—Typical Appearance of Tested Panel*

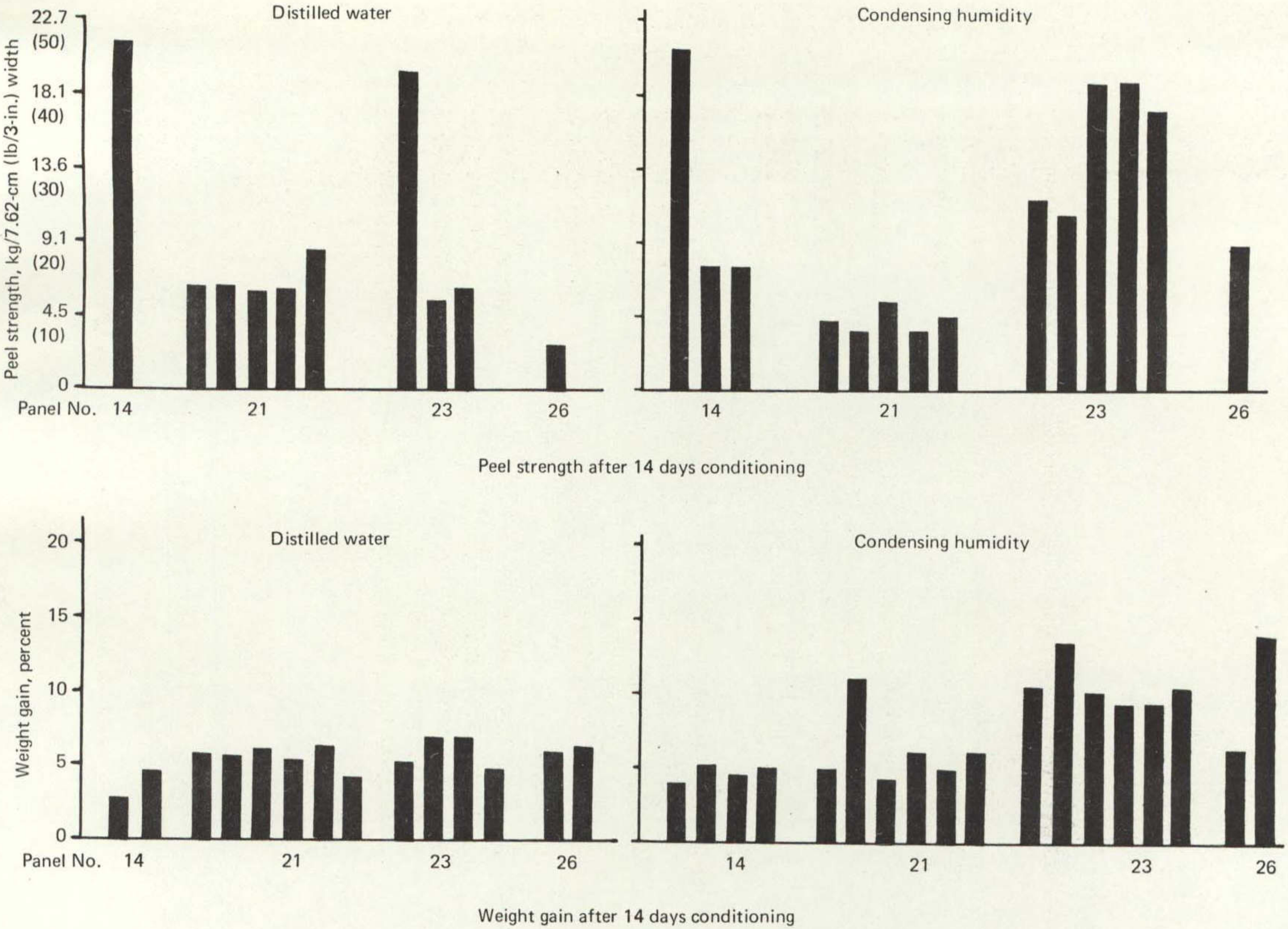



*Figure 30.—Environmental Exposure Test—Weight Gain*

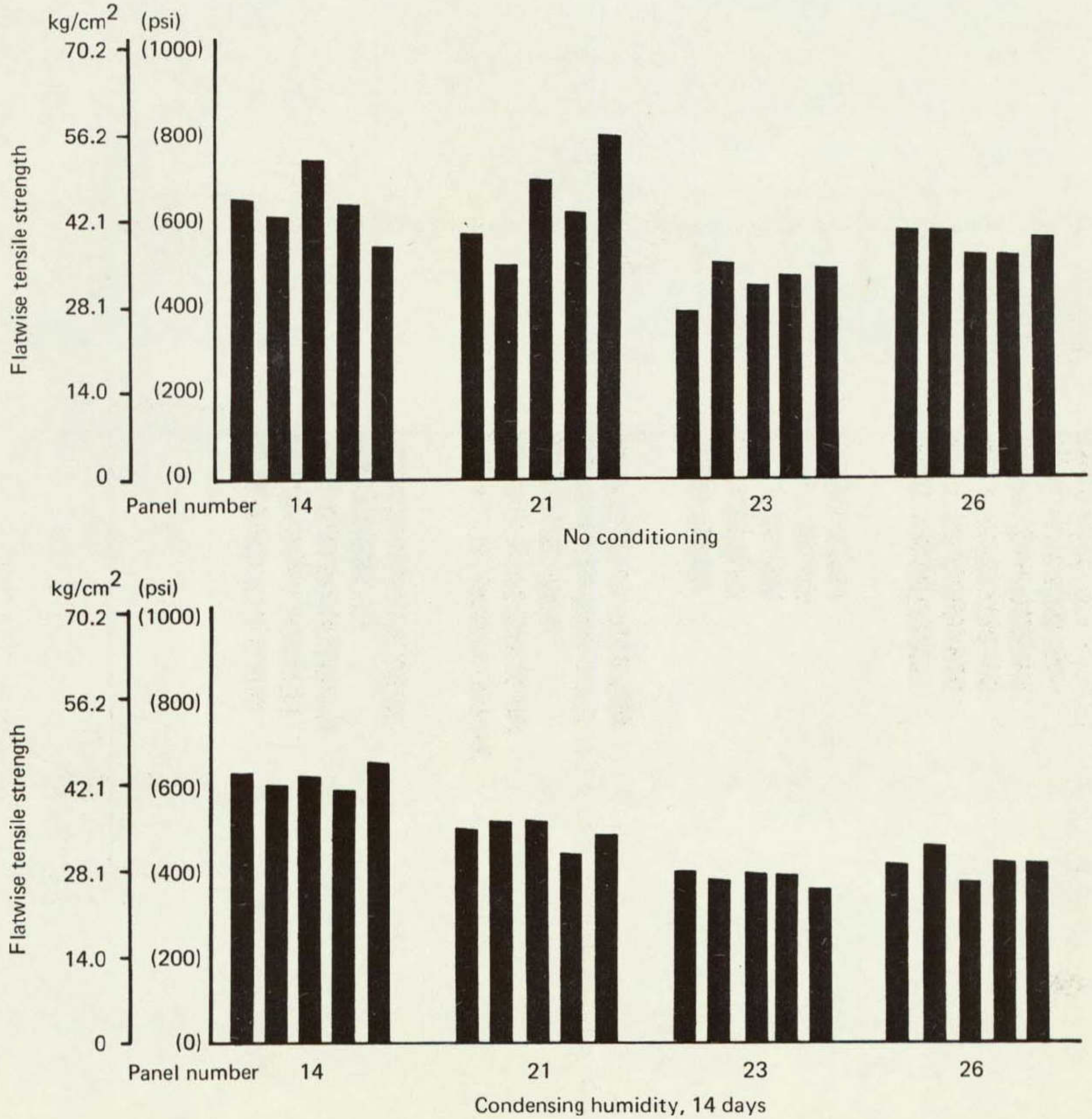



*Figure 31.—Environmental Exposure Test—Flatwise Tensile Data, Condensing Humidity*

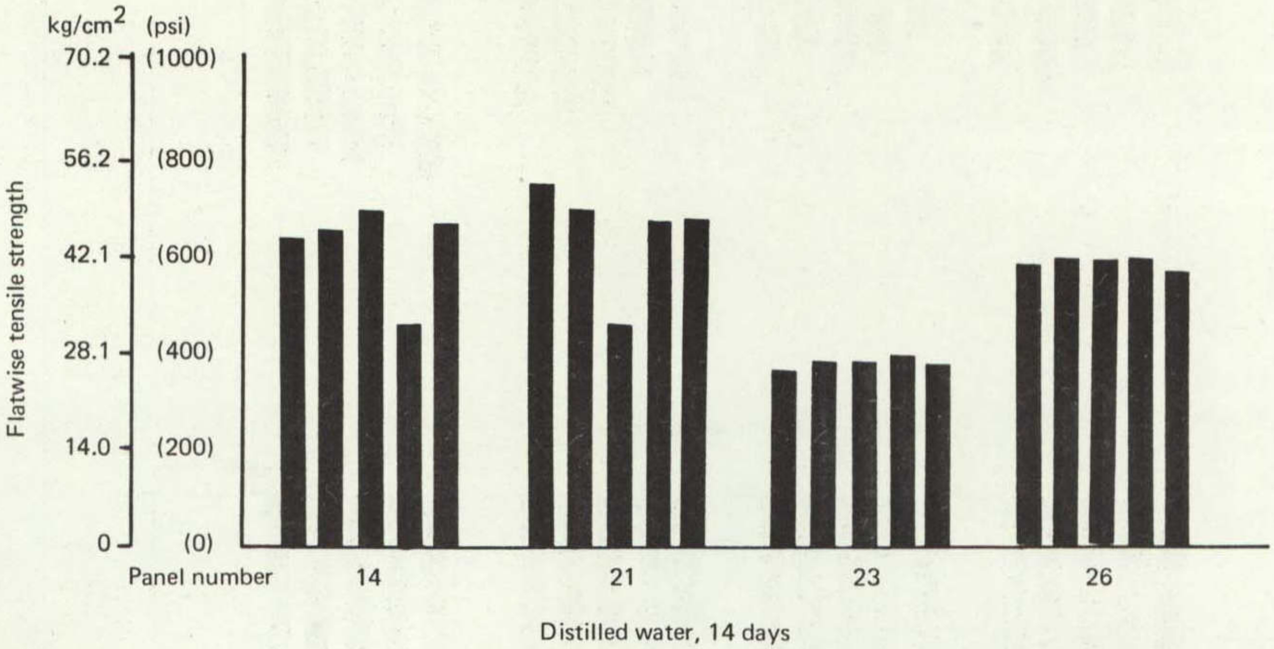
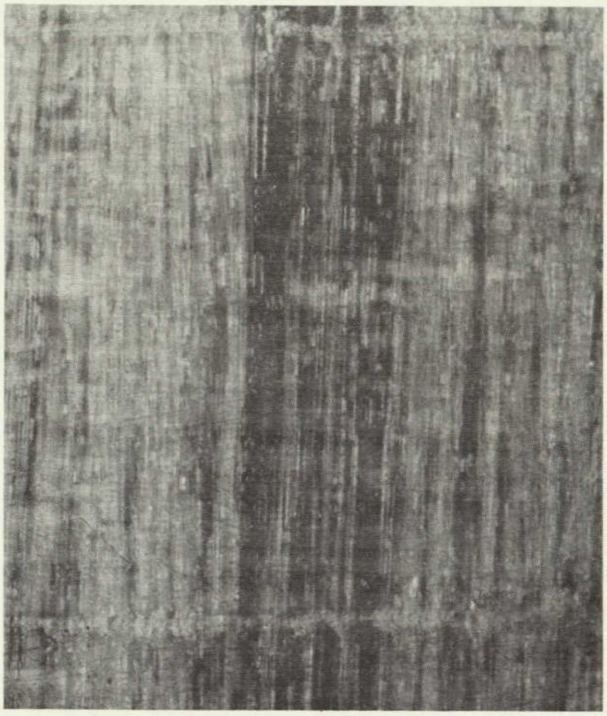
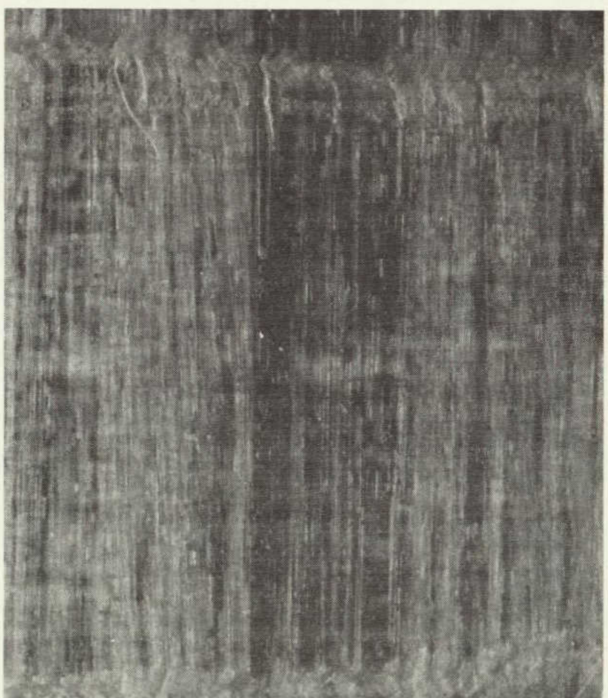



*Figure 32.—Environmental Exposure Test—Flatwise Tensile Data, Distilled Water*

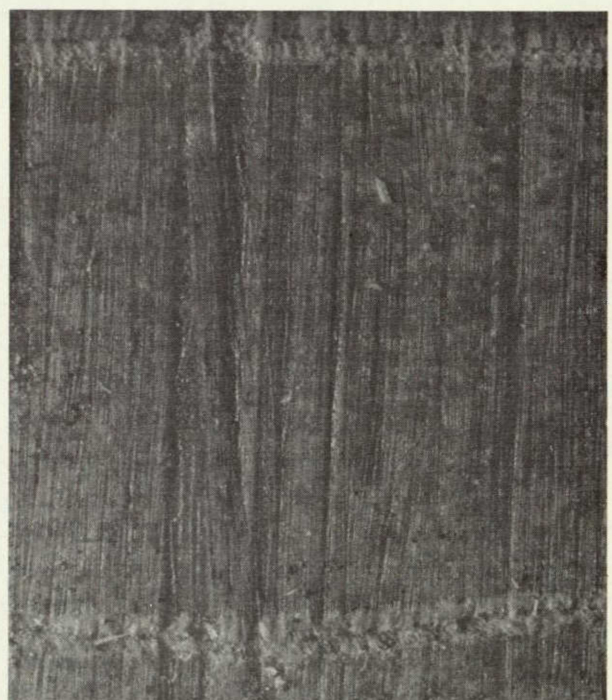


Panel 14, before

Panel 21, before

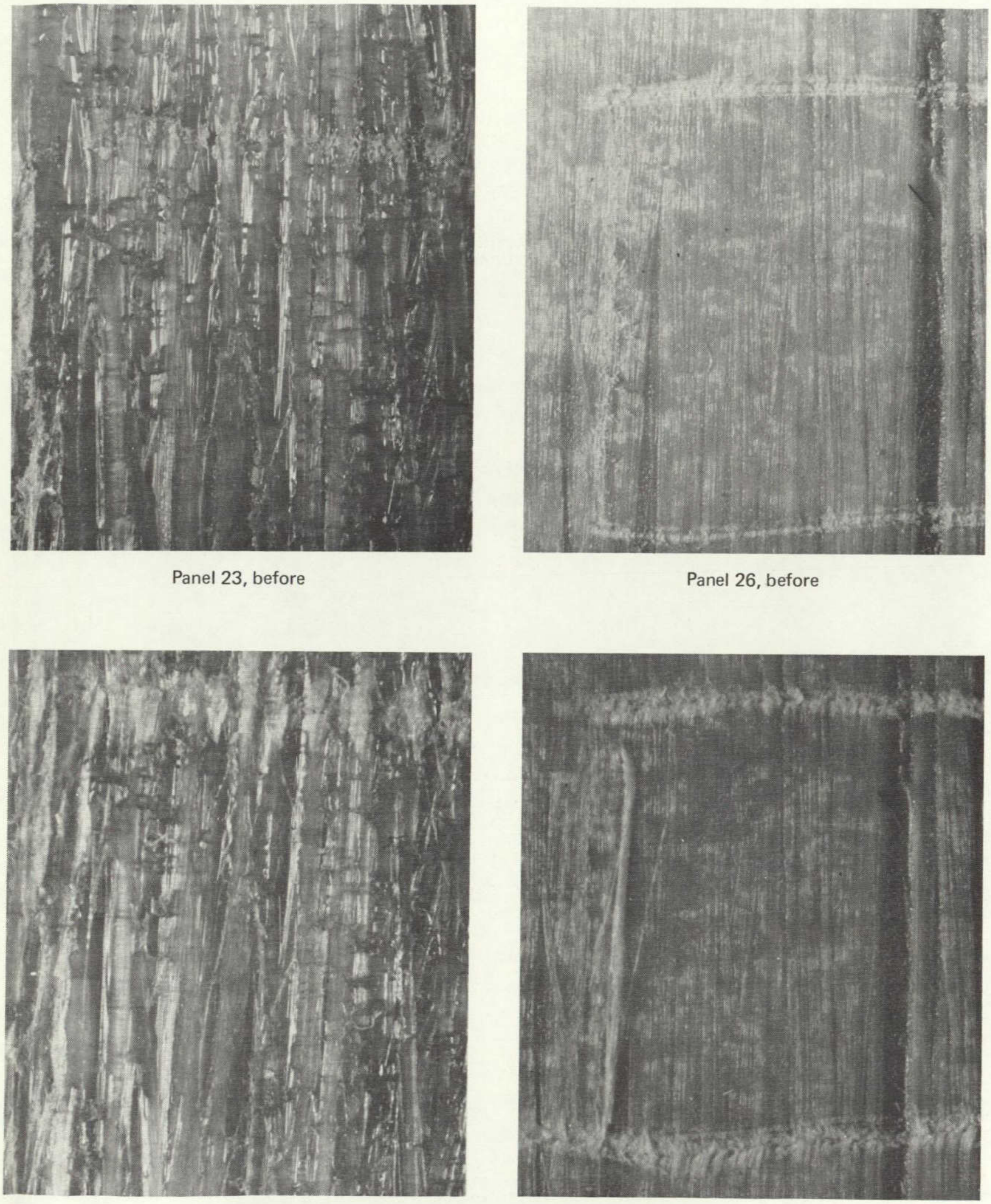


Panel 14, after



Panel 21, after

*Figure 33.—Effect of Salt Spray, Panels 14 and 21*



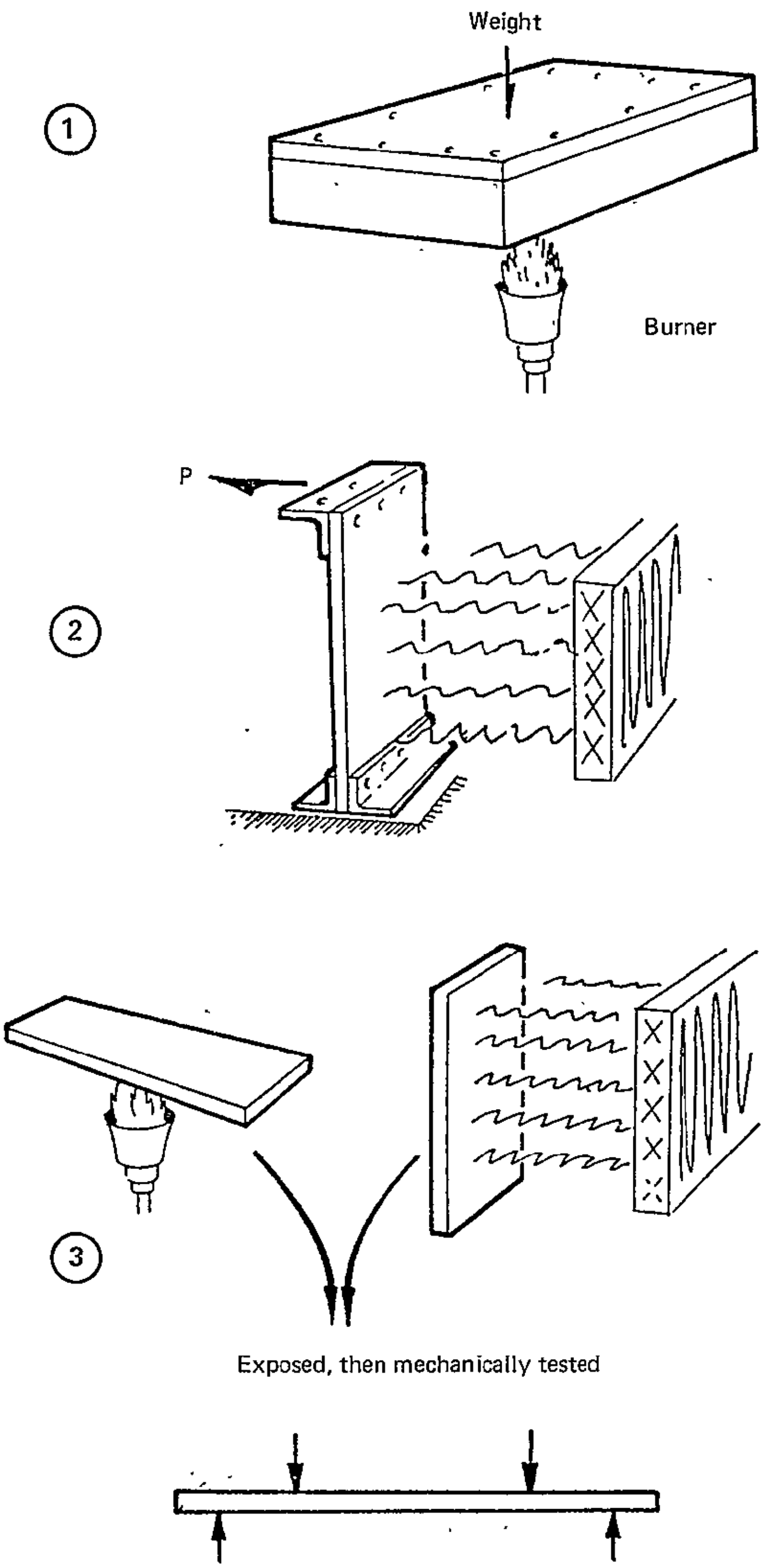
Panel 23, before

Panel 26, before

Panel 23, after

Panel 26, after

*Figure 34.—Effect of Salt Spray, Panels 23 and 26*




Burn-through with static weight

- Measure time to failure.
- Variables are heat flux and static weight.

Stressed coupon exposed to radiant heat panel, with or without open flame

- Measure time to failure.
- Variables are heat flux and load

Unstressed coupon exposed to radiant heat panel or open flame, subsequent static test

- Measure static residual strength.
- Variables are heat flux and load.

*Figure 35.—Suggested Flame Resistance Tests*

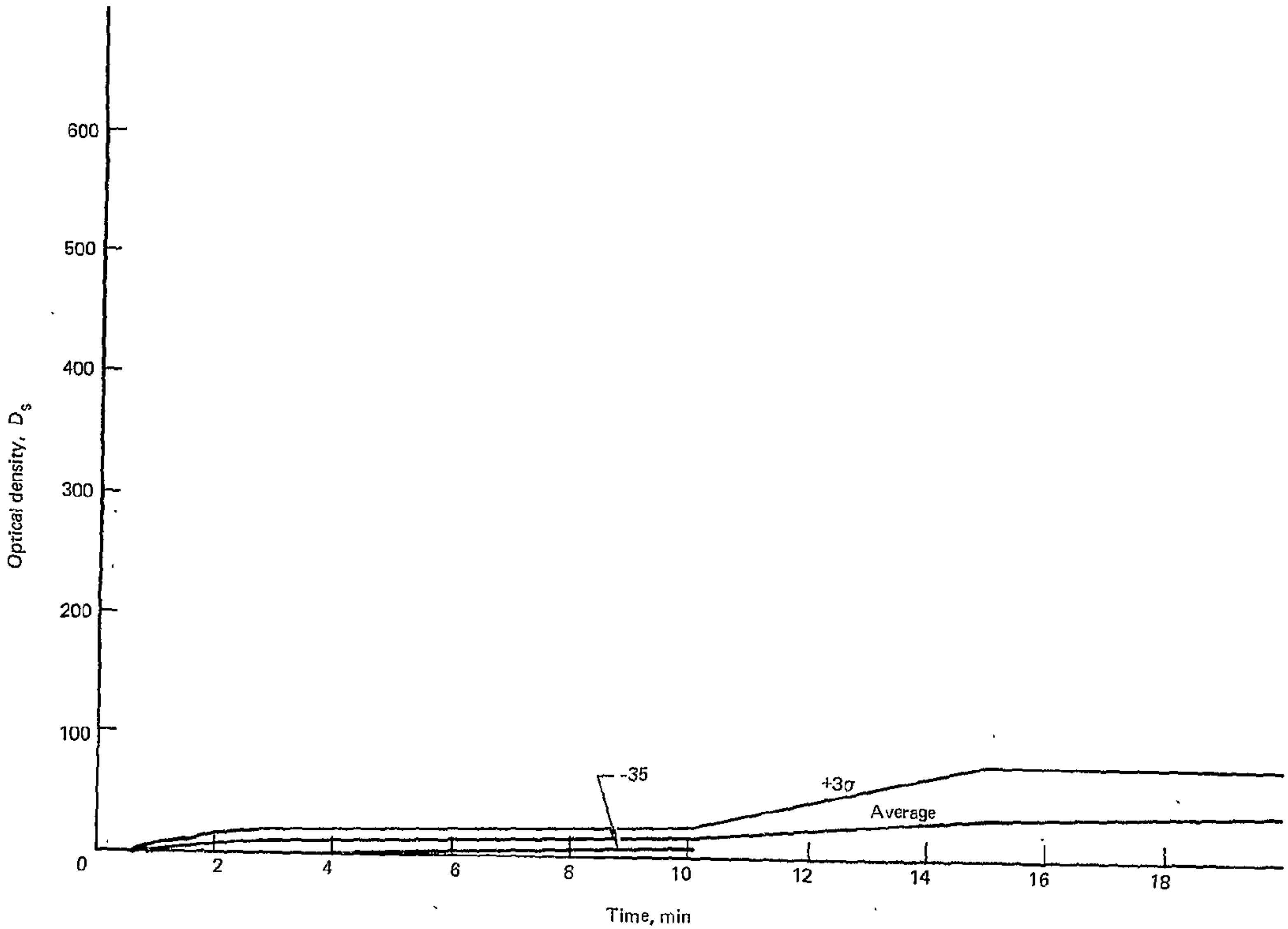



*Figure 36.—NASA-JSC Floor Panel 21, Flaming Mode, Statistical Smoke Density Curves*

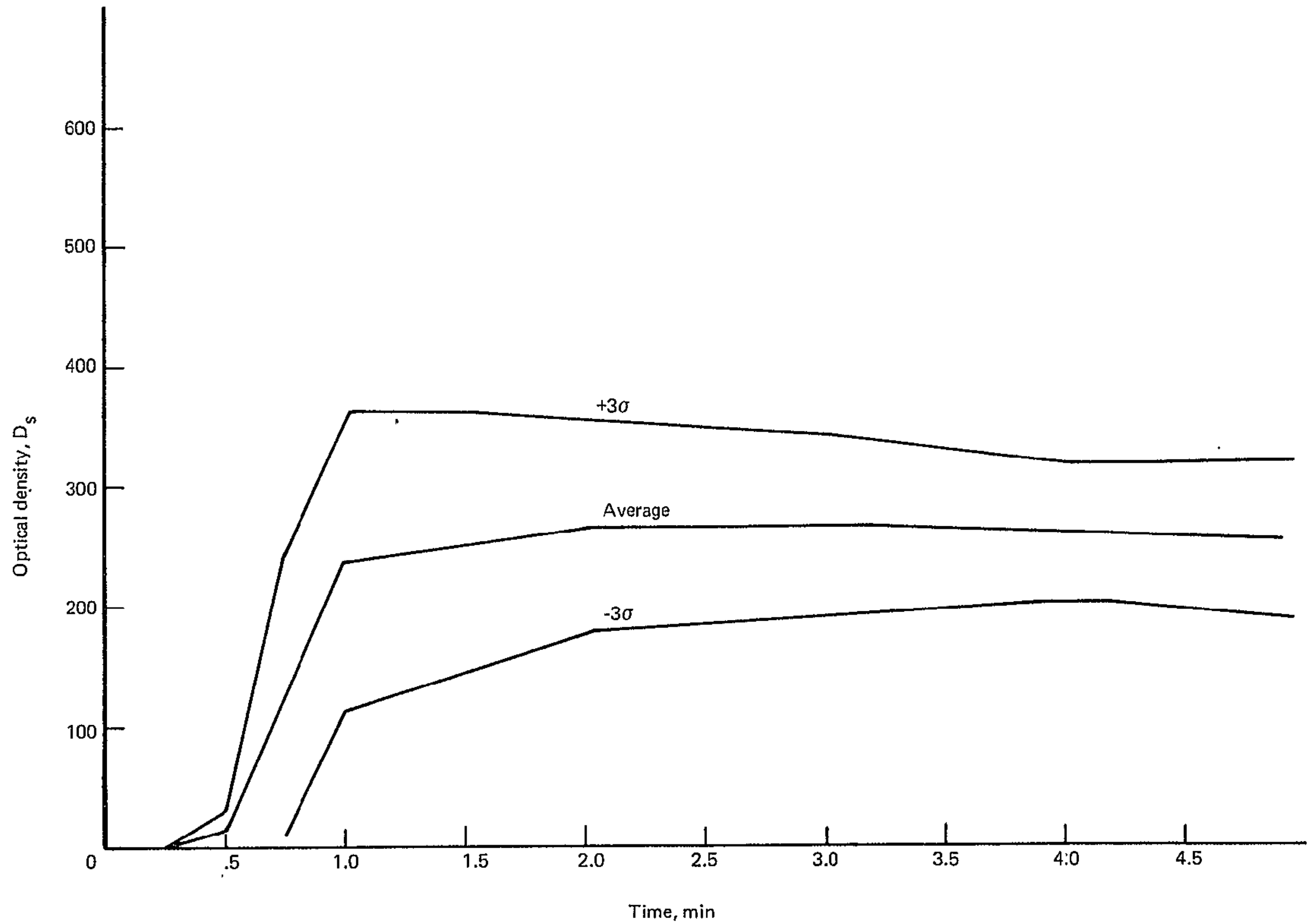



*Figure 37.—NASA—JSC Floor Panel 22, Flaming Mode, Statistical Smoke Density Curves*